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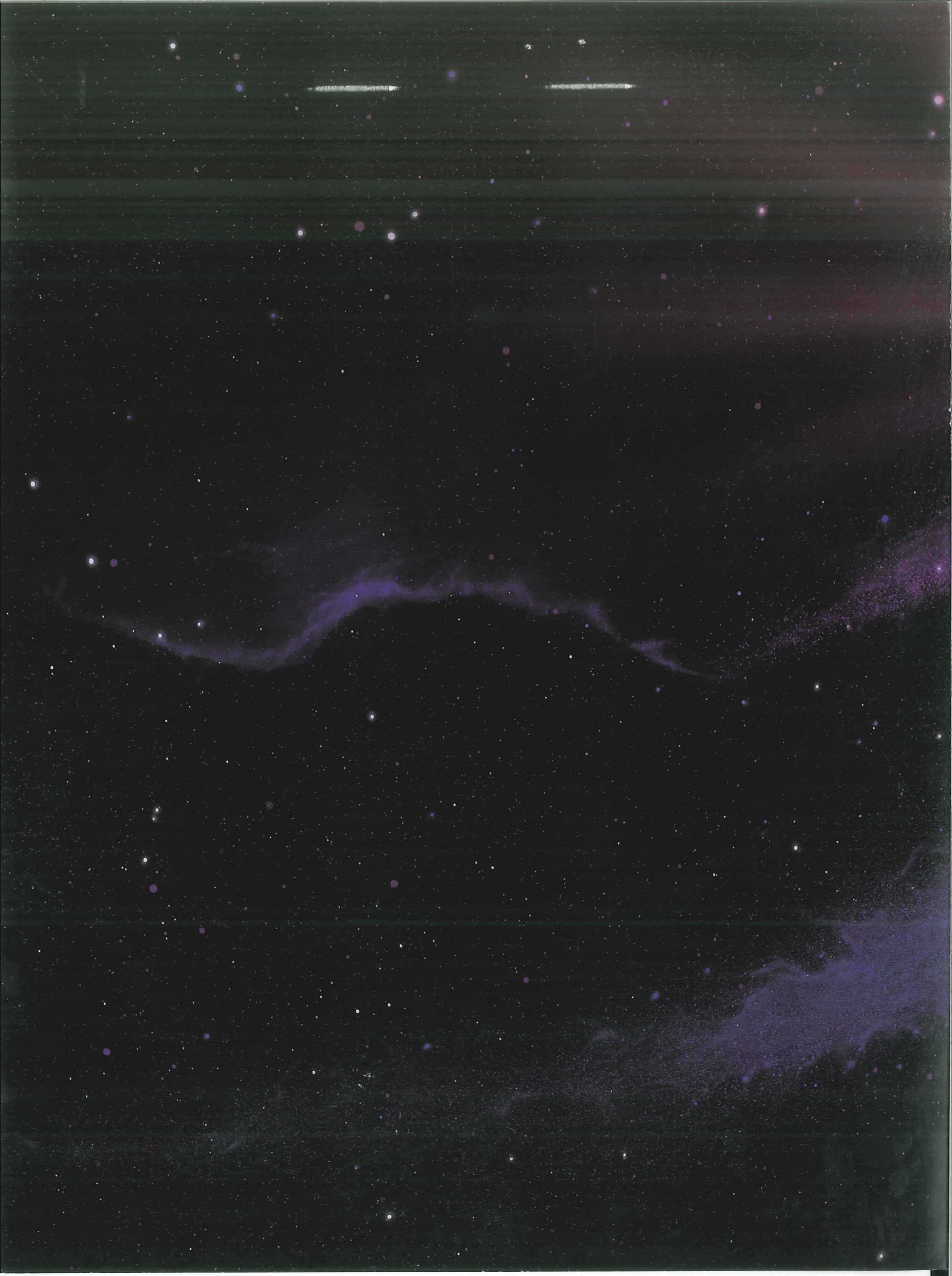
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SPACE LIFE SCIENCES

A Status Report



SPACE LIFE SCIENCES

Status Report
February, 1990

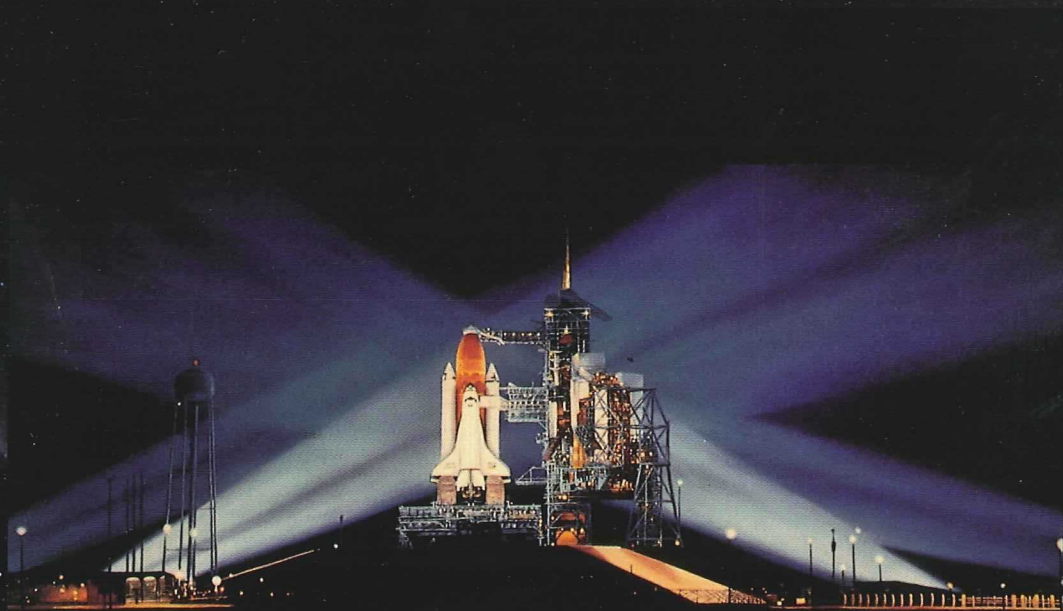
TABLE OF CONTENTS

Introduction	1
Overview	3
Operational Medicine Program	5
Clinical and Biomedical Programs	7
Space Biology Program	21
Controlled Ecological Life Support Systems Program	27
Biospheric Research Program	29
Exobiology Program	33
International/Interagency Cooperation	39
Educational Activities	43
Earth Benefits	47
Appendix A — Academic and Research Institutions Conducting NASA Life Sciences Research	51
Appendix B — Additional Reading	53



Life Sciences Division
Office of Space Science and Applications
NASA Headquarters

ORIGINAL PAGE
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INTRODUCTION

"We must commit ourselves anew to a sustained program of manned exploration of the solar system - and yes - the permanent settlement of space. We must commit ourselves to a future where Americans and citizens of all nations will live and work in space."

President George H.W. Bush,
July 20, 1989.

On the 20th anniversary of the Apollo 11 lunar landing, the President of the United States stood on the steps of the National Air and Space Museum and delivered a challenging imperative to the aerospace community. The President announced that the time has come to prepare for a return to the moon and travel to Mars.

Humankind now stands at an important crossroads: for the first time in the 4.5-billion-year history of terrestrial life, we will be entering a new environment - space - continuously and possibly permanently. This profoundly important biological event may turn out to be as significant as the transition of life from sea to land.

If the United States is to continue to lead the world in space exploration, and if NASA is to fulfill the national space policy goal of expanding human presence beyond Earth orbit, then scientists must determine how exposure to space affects life, from birth to death. The vision of human colonies living beyond the surface of Earth cannot materialize without the accumulation of a vast new store of fundamental knowledge in the life sciences.

NASA is now engaged in planning to fulfill the President's directive. Advances in medical support technologies and life support systems — two major thrusts of the Space Life Sciences Program — are key to such a large-scale initiative. The Space Life Sciences Program began in 1960 with a goal of enabling human survival in space. Since then, it has grown to encompass seeking an understanding of the basic mechanisms that

underlie space adaptation, predicting related health-threatening problems, and developing more effective countermeasures to mitigate the physiological effects of space flight. Through a combination of basic and applied research, space life scientists will acquire the biological and biomedical knowledge and the technological capability that one day will enable humans and other species to venture safely into Earth orbit and beyond.

"I'm proposing a long-range, continuing commitment. First, for the coming decade... Space Station Freedom — our critical next step in all our space endeavors. And next — for the new century — back to the Moon... And this time, back to stay. And then... a manned mission to Mars. Each mission should — and will — lay the groundwork for the next."

In his speech, the President outlined a step-by-step approach to extending human presence beyond Earth orbit. The Space Life Sciences Program is an evolutionary approach to ensuring human health and productivity on space missions, now on the Space Shuttle, later on Extended Duration Orbiter missions, then on Space Station Freedom, and ultimately on the moon and missions to Mars. Among the key goals of the Space Life Sciences Program are to assure crew health and well-being; to understand the role of gravity in the function and development of living systems; to understand the origin, evolution, and distribution of life in the universe; and to promote the application of life science research toward improving the quality of life on Earth. Attaining these goals depends upon the development of sophisticated laboratory facilities in space and the long-term, continuous availability of such facilities.

A strategic plan completed for the Space Life Sciences Program in 1989 lays out a research agenda in which Space Shuttle/Spacelab investigations point the way to research that will need to be done on Space Station Freedom. Ultimately, life sciences research on Freedom will be followed by lunar-base investigations into life

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support requirements and long-duration exposure to partial gravity and isolation. All of this research will be necessary to enable long-duration human missions to Mars.

In the near term, space life sciences investigations will focus on developing countermeasures to physiological deconditioning in microgravity; identifying an effective treatment for space motion sickness; and determining how to regulate the loss of body fluids during flight. Other problems requiring further study before humans undertake long-duration missions in space include radiation risks, life support, and air and water quality and toxicological contamination in the spacecraft environment. Research in space human factors will be a growing concern for the space station era and beyond; issues to be addressed include psychological stresses and responses related to isolation and confinement, and crew interactions in remote and potentially hazardous settings.

"We had a challenge. We set a goal. And we achieved it."

These words from the President, harking back to the Apollo Program, are a sound guide for any new space initiative. Our challenge in the Space Life Sciences Program is to determine how and why humans respond to the absence of gravity, radiation exposure, and other stresses inherent in space flight. Our goal is to learn exactly what happens to humans in space, which aspects of deconditioning are potentially harmful, and what

steps must be taken to counteract those effects. We will work toward that goal by conducting a carefully plotted series of progressive investigations on Space Shuttle missions, while planning for that time in the 1990s when we will be able to expand our research on Space Station Freedom. We will have achieved our goal when humans are living and working safely and productively beyond the bounds of Earth.

"Raise your eyes to the heavens and join us in a great dream."

The President issued this invitation to the children who today may not be thinking about missions to Mars but tomorrow may be living and working there. The Space Life Sciences Program sponsors many educational activities for students in grade school, high school, and college, with the hope that these activities will help to ensure an adequate force of scientists and engineers to fulfill the President's vision in coming years.

In 1989, through the Extended Duration Orbiter (EDO) Medical Program, we pursued life sciences investigations on almost every Space Shuttle flight, launched cooperative experiments on a Soviet biosatellite, and completed planning for the first-ever Space Shuttle/Spacelab mission entirely dedicated to life sciences research, Spacelab Life Sciences 1 (SLS-1). As the turn of the century approaches, the Space Life Sciences Program will play an expanding role in enabling humankind to be a spacefaring race.

The Space Life Sciences Program achieved a broad range of accomplishments in 1989. Life sciences investigations flew on almost every Space Shuttle mission last year, including several that initiated an Extended Duration Orbiter (EDO) Medical Program newly established in 1989. And NASA-sponsored investigators cooperated in experiments flown on a Soviet Cosmos biosatellite mission launched in September.

In 1989, planning was completed for the first Space Shuttle mission that will be entirely dedicated to life sciences research — Spacelab Life Sciences 1 (SLS-1), to be launched in August 1990. This mission will firmly establish the Space Life Sciences Program as a flight program.

A Telemedicine Spacebridge between the United States and Soviet Armenia was established in 1989 to provide medical assistance to the victims of the Armenian earthquake of December 1988. The Spacebridge was so successful that it was extended to the Soviet city of Ufa to provide medical assistance to victims of the May 1989 train wreck in that area.

As part of the Space Life Sciences Program's comprehensive study of physiological deconditioning in space, a five-week bedrest study of six subjects and a 120-day bedrest study of two subjects were initiated in 1989. Ground-based studies such as these investigations supplement the limited flight opportunities available for studies in microgravity. In anticipation of future long-duration human missions in space, NASA life scientists renewed the study of how artificial gravity can be used as a countermeasure. In addition, a systems engineering study for a Variable Gravity Centrifuge, to be installed on Space Station Freedom, was completed.

A CELSS flight program plan was prepared in 1989, while ground-based experiments proceeded with soybean production,

convention of inedible biomass, and the viability of lunar-derived soils for plant growth. The Biospheric Research Program continued studies of how biological processes affect planetary conditions, focusing on phenomena such as biomass burning and global methane fluxes. The Search for Extraterrestrial Intelligence (SETI) Microwave Observing Project began field tests of prototype signal detection and processing hardware and radio frequency interference (RFI) measurement systems.

The role of international and interagency cooperation in the Space Life Sciences Program grew in 1989. Cooperative activities proceeded with Canada, France, Germany, Japan, the European Space Agency, and the U.S.S.R. A Joint Working Group was established with the National Institutes of Health to pursue opportunities for joint research, and discussions were initiated with the Environmental Protection Agency regarding interests in joint research into the effects of global warming on aquatic systems.

In the area of educational activities, the Space Life Sciences Program, an undergraduate summer-school session cosponsored by the Space Life Sciences Program and NASA's Office of Equal Employment Opportunity, completed its fifth year and reported great success. An SLS-1 Educational Project was established to develop high-school curriculum materials tied to the SLS-1 mission. And for Fiscal Year 1990, the Space Life Sciences Program established a NASA Specialized Centers of Research and Training (N-SCORT) program to support pre- and post-doctoral fellows and other scientists at participating organizations.

This report describes the scientific research and supporting technology development conducted in the Space Life Sciences Program. Accomplishments of the past year are highlighted throughout the text. The report also outlines plans for future activities.

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CREW HEALTH AND SAFETY

OPERATIONAL MEDICINE PROGRAM

The Life Sciences Division's Operational Medicine Program is intended to ensure crew health, safety, and productivity during space missions. This goal is accomplished by practicing preventive, occupational, and clinical medicine and establishing the effectiveness of appropriate medical countermeasures and life support systems in flight. Operational Medicine activities include preflight and postflight medical evaluations of crew members, physical and environmental health monitoring and maintenance during flight, emergency medical support, and maintenance of a database to identify long-term adaptive mechanisms to single and multiple exposures to space flight.

1989 Activities

At Johnson Space Center, medical researchers recently developed a new **Aeromedical Database** that will give NASA physicians immediate access to information on space flight experience and medical history for all space crew members in case of on-orbit illness or emergency landings. The database can be stored on tape, floppy or hard disk, or laser card; it can be used with a laptop or personal computer and hence is mobile. This database ultimately will be used in the Health Maintenance Facility on Space Station Freedom.

JSC scientists have also developed a **Medical Toxicology Database** to provide rapid access to information on potential on-board toxins during Space Shuttle missions as well as medical treatment options in case of contamination. The database provides information on characteristics and hazards of on-board toxins, exposure limits, and cleanup procedures. Another new development is a **Microgravity Eye-Wash System** for crew members to use in case of chemical contamination in the Shuttle cabin.

Crew performance in microgravity can be tested on KC-135 flights.

The Life Sciences Division signed a memorandum of understanding with the U.S. Air Force in 1989 to cooperate on Operational Medicine projects of mutual interest. The first meeting of a NASA-USAF Joint Working Group took place in late 1989.

Physicians with the Operational Medicine Program also participated in a **Telemedicine Spacebridge** with Soviet physicians that operated for several months in 1989 (*see p. 40*). In addition, they continued evaluating available medical support at several Space Shuttle transatlantic abort landing (TAL) sites — two in Spain, one in Morocco, and one in Gambia.

Future Activities

NASA officials are now negotiating agreements with administrators of hospitals at each of the TAL sites to provide medical support in case of emergency Shuttle landings.

A prototype surgical work station for Space Station Freedom's Health Maintenance Facility will be used for the performance of in-space verification tests of surgical techniques on Spacelab Life Sciences 1 and Spacelab J. The verification tests will cover emergency surgical and medical procedures, including restraint mechanisms and the ability to control, contain, and collect fluids.



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Working in Space: The Telescience Testbed

Telescience is a research method that enables the effective conduct of medicine and science in space through the use of offsite resources, including people. On future Space Shuttle and Space Station Freedom missions, audio and video channels and networked computer work stations will permit physicians on Earth to treat patients in space.

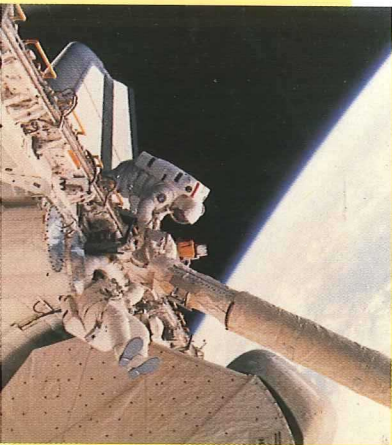
This technique can also link payload operations managers at NASA field centers and principal investigators at their research institutions with crew members in space so that they can work together on biomedical, space biology, and other experiments in real time. Telescience will be especially useful to life scientists because space crew members may serve as experimenters and test subjects, and because unexpected developments may require principal investigators to make real-time decisions about test conditions or data collection.

A Telemedicine Spacebridge set up in 1989 (see p. 40) linked physicians in several Earth-

based locations and demonstrated that the Spacebridge may be a viable means of providing in-flight medical services to space crew members. Researchers at NASA's Kennedy Space Center and the Massachusetts Institute of Technology are developing a telescience testbed for biomedical investigations in space. And NASA's Ames Research Center has developed a telescience testbed to support space biology and other investigations in orbit.

The Life Science Telescience Testbed facility at Ames consists of a prototype space station glovebox (a biological isolation chamber to keep specimens and researchers separated), networked computers, closed-circuit television cameras and monitors, a small robot to handle routine tasks such as cleanup, and other related hardware. In experiments conducted at the testbed, life science researchers act as space-based mission specialists, interacting with other researchers posing as ground-based payload operations managers and principal investigators. Failures such as garbled computer commands and loss of audio link are built into experiment simulations to observe how research participants might respond.

The intent of the demonstrations is to show that this technique can save valuable crew time, enhance productivity, and improve the quality of science. Simulations thus far have shown that the availability of audio, visual, and computer workstation information in telescience can improve the quality of science. Participants in the simulations have reported that electronic checklists of experiment procedures provided by computer proved useful. Further demonstrations will build on what has been learned from these initial tests.



Ensuring health and safety during extravehicular activity is a primary concern.



Telescience provides a way for scientists on Earth to work with crew members in space.

WHAT HAPPENS TO HUMANS IN SPACE?

CLINICAL AND BIOMEDICAL PROGRAMS

Based on what they have learned to date about the effects of space flight, life scientists have identified four major problems that could threaten to limit the duration of human stays in space: physiological deconditioning, exposure to space radiation, human factors issues inherent in long-term flight, and maintenance of a habitable environment. These problems require further study before decisions can be made to send humans on space missions of a year or longer. Research sponsored by the Clinical and Biomedical Programs addresses these and other issues related to human stays in space.

During space flight, humans undergo a spectrum of changes: bone mineral content declines, muscle mass is lost, heart function is altered, and body fluid content and red blood cell count drop. Virtually all body systems are affected by exposure to microgravity. How far these changes may progress with time in space is largely unknown.

The objective of NASA's Clinical and Biomedical Programs is to understand — and ultimately to overcome — the physiological, psychological, and sociological obstacles to extended human space flight. The development of suitable countermeasures to physiological deconditioning, protocols to optimize crew performance and productivity, and operational life support systems is critical to achieving this goal.

Cardiovascular/ Cardiopulmonary Research

Exposure to the microgravity environment of space affects the function of the heart, blood vessels, and lungs. Body fluids shift to the upper body upon initial exposure to microgravity, causing the heart to enlarge so that it can handle increased blood flow.

Pressure in the arteries rises, triggering mechanisms through baroreceptors (pressure receptors) in the heart and major arteries that signal the brain to adjust heart rate and maintain normal blood pressure.

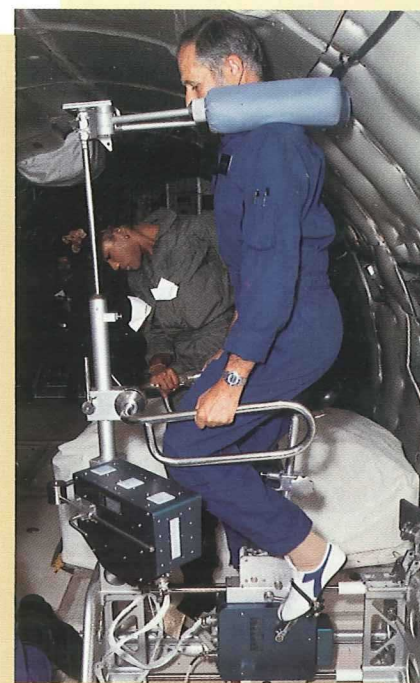
The fluid shift appears to peak in 24 hours, and the heart reaches a new steady state of operation in three to five days. Gravity also plays a major role in the operation of the cardiopulmonary system — ventilation, blood flow, gas exchange, and pressure in the lungs are affected by gravity. The cardiovascular/cardiopulmonary system interacts with every organ in the body, and small changes in this system may propagate throughout the body.

Upon return to Earth, the body must readapt to Earth's gravity. Fluids pool in the legs upon standing, the heart beats rapidly but blood pressure often falls, and exercise capacity is reduced. Back on Earth, the cardiovascular system usually takes a few days to several weeks to return to normal depending on the duration of the flight, but the mechanisms that cause the system to adapt and readapt are not well understood. Investigations in space and on the ground should shed light on how these changes occur.

1989 Activities and Accomplishments

Human subjects have been kept immobile for up to 120 days in bedrest studies sponsored by the Space Life Sciences Program. These studies are an important ground-based technique for studying how gravity loads affect bones and muscles because immobilization simulates many aspects of weightlessness.

Several bedrest studies are now under way, sponsored by NASA or jointly by NASA and foreign partners. Researchers are working on the standardization of protocols and measurement methodologies for ongoing studies.



Exercise countermeasures are tested on the KC-135 aircraft.

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Studies conducted to date at Ames Research Center's Human Research Facility, the Baylor Clinical Facility, and the University of Texas Clinical Facility indicate that exercise and weight bearing are necessary to counteract decreased gravity loads. Bedrest studies being conducted in conjunction with the French space agency Centre National d'Etudes Spatiales (CNES) focus on the types and duration of countermeasures that may be required to maintain orthostatic tolerance.

JSC researchers are using bedrest studies to investigate calcium loss and chemical countermeasures; **a five-week study of six subjects and a 120-day study of two subjects were initiated in 1989.** Subjects in the five-week study experienced a decline in muscle mass and strength; a 12 percent decrease in size was roughly equivalent to a 25 percent decrease in strength, and this 1:2 ratio was seen in all muscles examined. Bone loss generally is not measurable until a subject has been immobilized for eight weeks, but subjects in the five-week study did experience a decline in whole-body calcium. Bone biopsies were taken from subjects in the 120-day study before immobilization and in the last two weeks of immobilization for comparison of bone mineral content. Bone density, nutrition, and other factors were checked weekly during this study.

A research team sponsored by JSC has validated the seven-day bedrest study as a model of human muscular inactivity during space flight. In addition, bedrest studies conducted by this team have yielded significant measurable muscle weakness and deterioration. Rates of protein breakdown and synthesis have been measured before and after bedrest. The team has measured changes in anabolic (growth-promoting) and catabolic (growth-inhibiting) hormones brought on by bedrest and also characterized bedrest-related changes in glucose metabolism: insulin-stimulated glucose use decreased significantly during seven days of bedrest.

Data are now available on the results of a 30-day bedrest study conducted at the ARC Bedrest Facility by researchers at ARC, KSC,

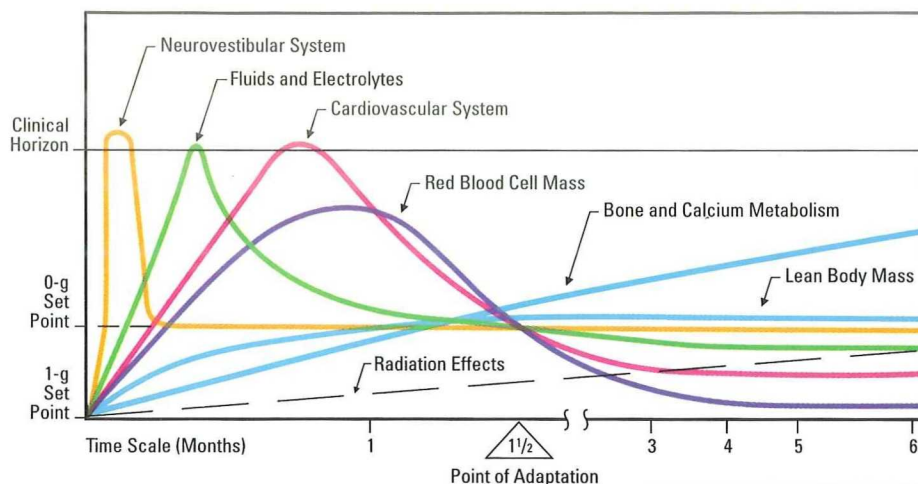
and Virginia Medical College with 10 subjects. Four failed a five-minute-stand test following bedrest because of faintness, and six were able to pass the test, but with a significant rise in heart rate similar to that experienced by astronauts who have not used countermeasures in space. Researchers found that the individuals who were prone to faint were those whose carotid baroreflex — that is, the ability of baroreceptors in the carotid arteries that carry blood through the neck to the head to maintain normal blood pressure — was most impaired. For longer-duration space flights, a countermeasure to this baroreflex adjustment may be necessary.

Future Activities

The KSC team is evaluating highly intensive exercise as a possible countermeasure because it appears that one bout of maximal exercise may cause a baroreflex adjustment that is the opposite of the adjustment caused by bedrest. A possible outcome of this study could be an exercise countermeasure program for space crew members. Bedrest studies will continue, and a comprehensive series of cardiovascular/cardiopulmonary investigations will be flown on the Spacelab Life Sciences 1 (SLS-1) mission (*see p. 13*). Further investigations will be flown on subsequent Space Shuttle missions to build on what is learned from SLS-1.

Bone and Muscle Research

The cause of bone and muscle atrophy in space and the way in which it affects crew members' performance are the subjects of current biomedical investigations. Bone cells called osteoclasts carry minerals out of bones into the bloodstream; new bone is formed by cells called osteoblasts. In humans, these cells require about one month to undergo a complete cell cycle. Research on Space Station Freedom will provide an opportunity to observe how the human skeletal system responds to long-term microgravity exposure. NASA researchers need to identify the processes that control bone mineralization so



that they can develop countermeasures to mineral loss in space. Future flight investigations will address specific cellular and extracellular mechanisms of bone metabolism and the process of bone healing.

1989 Activities and Accomplishments

Researchers now believe that exposure to microgravity may cause an uneven distribution of calcium in weight-bearing bones. Postflight analyses of bone samples, characterizing the regional distribution of minerals and collagen matrix (collagen is the fibrous connective tissue in bone), showed that mineral concentrations declined from the upper to lower ends of the bone shaft — that is, from the end that would be farthest from the source of gravity (Earth) to the end that would be closest to gravity. This phenomenon was studied in **an experiment flown on a Soviet Cosmos biosatellite mission in 1989**. For documenting bone density gradients in space crew members, researchers are now considering an analytic technique called whole-body calcium screening, which produces a computerized picture of bone density throughout the body.

Ensuring sustained high-level crew performance during long-duration space flights will be a limiting factor in planning for future missions. **In 1989, the Life Sciences Division initiated a three-year Extended Duration Orbiter (EDO) Medical Program** intended to ensure the health, safety, and productivity of crew members on EDO Space Shuttle missions of 16 days, especially during landing and egress.

Through ground-based research and Space Shuttle investigations, life scientists will study exercise capacity, cardiovascular and neurosensory function, and environmental factors as they relate to extended stays in space. EDO medical investigations were booked on STS 28, 34, 33, 32, 36, and 31 in 1989 and 1990, and the first EDO mission, planned for 16 days, will be launched in the spring of 1992. The International Microgravity Laboratory 2 mission manifested for January 1993 has been proposed as the final verification mission for the 16-day-mission protocols and prescriptions to be developed under the EDO Medical Program.

Researchers are studying how gravity helps to maintain muscle size and strength by increasing tension on muscle cells. Using tissue culture, they are studying the relationship between gravity and muscle condition. They have already discovered that hormonelike substances called prostaglandins play a role in tension-induced muscle growth by regulating protein turnover in muscles. These investigations ultimately may permit biomedical researchers to develop pharmacological methods of preventing muscle deterioration in microgravity.

Another NASA-sponsored investigation addresses why slow-twitch muscles — skeletal muscles that work against gravity to maintain body posture — atrophy so quickly and extensively in the absence of gravity. This investigation has documented a loss of 80 percent of contractile protein in the soleus (leg) muscles of rats after four weeks of simulated microgravity. It has also shown that the rate at which an organism synthesizes contractile proteins declines rapidly within

hours after the removal of gravity loads. The next step will be to identify the mechanisms that slow down this protein synthesis rate. Preliminary indications are that the process by which messenger RNA (ribonucleic acid) directs the making of contractile protein slows down in the absence of gravity.

Other researchers are studying the role of neurotransmitters — chemicals that help to relay neural impulses — in muscle atrophy. A certain type of neurotransmitter called a B2-adrenergic agonist appears to retard skeletal muscle atrophy. The adrenergic agonist clenbuterol, administered orally to rats for two to three weeks in ground studies, reduced the loss of protein content in soleus muscles. It appears that agents such as clenbuterol may retard the atrophy of slow-twitch muscles and promote the growth of fast-twitch muscles. Administered to space crew members along with a limited exercise program, clenbuterol may be an effective countermeasure to muscle deterioration in the absence of gravity.

Future Activities

One recent research advance is that biopsy specimens of muscle tissue can now be obtained from astronauts under local anesthesia; the first in-flight biopsy was taken on STS 34. Different techniques are being assessed for in-flight non-invasive monitoring of muscle mass and function, including nuclear magnetic resonance imaging, spectroscopy, and ultrasound. (Non-invasive monitoring does not require any instruments to enter the body.) Testing of possible countermeasures, such as exercise regimens, electrical stimulation, and hormone treatments, is being planned for near-term flights.

Ground-based studies of bone deterioration in rodents indicate that a non-steroidal, anti-inflammatory drug can inhibit bone demineralization and allow bone formation to continue in young, rapidly growing rats and older rats as well. Future ground-based studies will investigate whether this drug will slow down bone demineralization caused by immobilization.

Countermeasures Research

The Skylab missions of the 1970s showed that exercise is an important countermeasure to physiological deconditioning in space. Recent biomedical investigations have revealed that the type of exercise is an important variable that must be considered in determining its effectiveness.

1989 Activities and Accomplishments

Through ground- and space-based experiments using astronauts as subjects, a **JSC Exercise Countermeasures Project** will study the body's response to specific, controlled forms of exercise designed to lessen the effects of space adaptation. The goal is to develop a comprehensive exercise program, including individualized exercise prescriptions and interactive exercise equipment, that will ensure crew health, safety, and efficiency during flight. Muscle performance characteristics such as strength and endurance will be examined before and after flight, and the information will be used to create a baseline against which the effects of in-flight exercise can be evaluated.

To support this research initiative, the Exercise Countermeasures Project has developed a computer-controlled software package that can automatically adjust the difficulty of an exercise session as training progresses.

KSC researchers are investigating how different types of exercise affect different types of muscles, toward developing effective countermeasures for deconditioning during space flight. Recent investigations have shown that one strenuous exercise period (15-20 minutes) within 24 hours of reentry may help prevent postflight orthostatic intolerance. An effective countermeasures program may determine an individual's "baseline" condition and tailor a countermeasures regimen for that individual that will maintain that baseline.

Orthostatic intolerance — a tendency to faint as blood rushes to the lower body upon return to Earth's gravitational field — is one aspect of

deconditioning that requires attention, especially in preparation for Extended Duration Orbiter missions where crew members will have to be capable of landing the Space Shuttle. Reducing or eliminating orthostatic intolerance upon return to Earth gravity is important because the performance of space crew members may be compromised by extended exposure to microgravity.

Future Activities

A possible countermeasure to the problem of orthostatic intolerance will be tested on future Space Shuttle flights — a combination of oral rehydration (loading up on saline fluids at the end of a flight) and exposure to lower-body negative pressure (LBNP), which applies suction to force fluids from the upper body to the lower body, countering fluid shifts that occur in response to microgravity. This protocol may be expanded into an end-of-mission regimen for space station and interplanetary crew members.

Technology Development

The LBNP device flown on space missions to date is a large, fixed unit that immobilizes crew members. **A stowable, portable version of the LBNP device has been developed** and scheduled for its first flight on STS 32 at the end of 1989. The new LBNP device is a collapsible unit that requires only half a middeck locker of storage space. The portable device includes a 20-inch-diameter cylinder that fits around a crew member's body, only partially restricting movement.

NASA life scientists are looking for non-invasive methods of measuring physiological parameters in crew members, to assess their adaptation to microgravity without interrupting their work. Investigators at the Jet Propulsion Laboratory in California are working on a method for preflight and postflight measurement of muscle volume, using magnetic resonance imaging (MRI), to gauge muscle loss in microgravity. The researchers have developed an imaging protocol and tested it on 19 subjects in a 30-day bedrest study conducted at Ames Research

Center. They are now refining their MRI image analysis technique to measure the volumes of individual muscles. In 1990, this line of research will be extended to develop an ultrasound method of measuring muscle volume and to calibrate this method with the MRI method. The ultrasound measurement technique will be particularly useful because it can be used easily for in-flight measurements as well as preflight and postflight assessments.

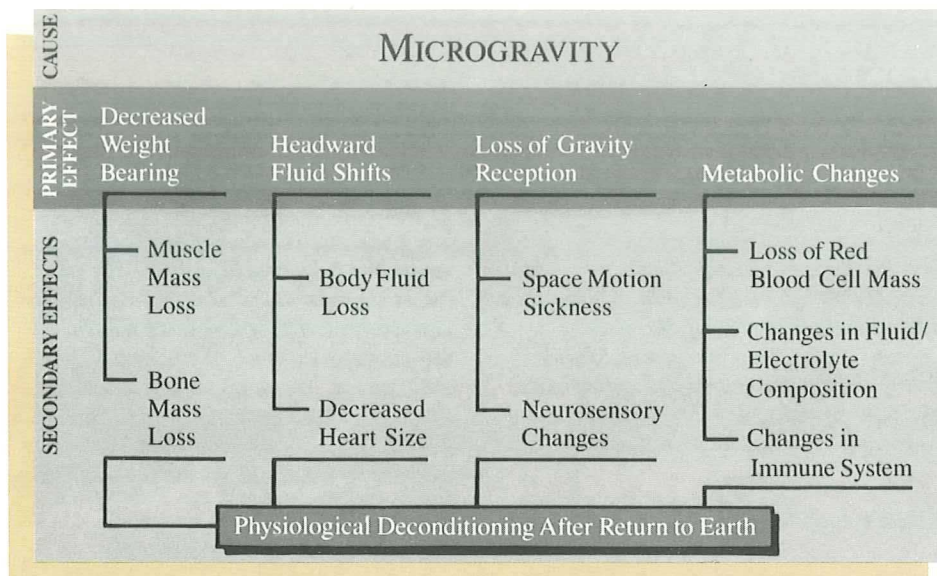
Neurovestibular Research

The human neurovestibular system serves as a biological inertial guidance system, controlling eye movements, posture, and locomotion. Ames Research Center's Vestibular Research Facility (VRF) is being used to study how variable gravity levels affect this system.

1989 Activities and Accomplishments

The VRF, which became operational in 1989, includes a small centrifuge that provides the complex rotational stimuli required to test potential animal subjects for centrifuge investigations in space. The facility also features a small linear sled for generating linear acceleration; a larger, human-rated sled will be added soon. At the VRF, investigators are now studying the reflexive eye movements caused by linear acceleration. They also want to determine how humans might respond to the centrifugation (that is, artificial gravity) that may be required as a countermeasure to physiological deconditioning during long-duration space flight.

NASA's only human-rated centrifuge, also located at Ames Research Center, has recently been upgraded and **is now back in operation**. Using this facility, studies are in progress to assess crew performance, focusing on how visual surroundings affect crew members' ability to judge the location of objects. Experiments are also in progress to identify the psychophysical function that permits an individual to identify changes in g force levels. Meanwhile, **preliminary results of a U.S. experiment on a Soviet Cosmos biosatellite**



mission launched in 1989 indicate that neurovestibular adaptation among primate subjects was complete after 15 hours of flight.

study because microgravity inhibits gastrointestinal activity, slowing the absorption of orally administered drugs.

Space Motion Sickness

Space crew members must be at peak performance throughout a mission to ensure that their safety is not compromised and their work is completed. Space motion sickness, a transient event brought on by neurovestibular disturbances in the absence of gravity, has attracted much attention in the space biomedical field because it affects about half of all space crew members.

1989 Activities and Accomplishments

NASA-sponsored researchers are using a slowly rotating room as well as investigations on KC-135 aircraft parabolic flights to study the phenomenon of space motion sickness. The parabolic flight trajectory creates up to 30 seconds of weightlessness for each parabola, thereby providing short simulations of the microgravity of space flight. They are also studying how humans adapt to Coriolis forces; such forces would be generated by a spacecraft rotating to create an artificial gravity field.

Medications to combat space motion sickness are also under investigation; researchers have compared the effectiveness of some 40 drugs and found that a mix of scopolamine and diamphetamine is the best treatment tested thus far. Alternatives to oral doses of anti-motion-sickness medication are under

Future Activities

Future studies will attempt to determine whether the neurovestibular disturbances that lead to space motion sickness are caused by a mismatch between visual sensory data and vestibular sensory data (collected by gravity receptors of the inner ear) or normal responses from sensory systems not previously exposed to space flight conditions.

Pharmacokinetics/dynamics

The absence of gravity affects the ways in which the body distributes, metabolizes, and excretes drugs (pharmacokinetics) and the ways in which drugs affect individuals (pharmacodynamics). JSC researchers are investigating the pharmacokinetics and pharmacodynamics of operationally important drugs such as anti-motion-sickness medications, using bedrest studies and other ground-based study techniques. Researchers plan to evaluate a nasal dosage method as an alternative means of administering the anti-motion-sickness drug scopolamine during space flight. A research protocol governing the use of human subjects in studies of this dosage method is under evaluation by NASA and the Food and Drug Administration.

Artificial Gravity: An Option?

At two NASA workshops in 1989, researchers began outlining an artificial gravity research plan. Studies of the effects of slow rotation on human adaptation and performance have been in progress since 1960, but as the prospects for human missions to Mars loom closer, the need to determine whether artificial gravity will be necessary on long-duration missions grows stronger. Researchers will consider the effectiveness of rehabilitative centrifugation at the end of a long-duration mission, periodic exposure to artificial gravity throughout a mission, or constant exposure to artificial gravity as countermeasures to physiological deconditioning in space.

On the ground, studies will be conducted at facilities such as Ames Research Center's human-rated centrifuge and the VRF. The Ames centrifuge may also be used to investigate tradeoffs between exercise and g levels in space, an important consideration in evaluating artificial gravity as a countermeasure to space adaptation. Options such as a mix of intermittent exposure to hypergravity combined with an exercise program may be evaluated as possible countermeasures.

SLS-1: First Dedicated Space Life Sciences Laboratory

In the summer of 1990, NASA will launch the first Space Shuttle mission entirely dedicated to space life sciences research. **Spacelab Life Sciences 1 (SLS-1)**, the first Spacelab module mission since before the Challenger accident, has been in preparation since 1978. Proposed by an international team of established investigators, the 20 flight investigations selected for this mission were carefully chosen to comprise an integrated package of measurements and observations that collectively will address

some important questions about how living systems adapt to the microgravity environment of space and readapt to one g upon return to Earth.

The general goals of the SLS-1 investigations are to understand the acute and long-term responses and adaptations of the living organism to the space environment and to ensure adequate physiological and performance countermeasures for humans in space. Data and specimen samples will be gathered from human and animal subjects. Spacelab Life Sciences 2, scheduled to fly in 1992, will carry follow-on experiments to those on SLS-1.

The 20 experiments on SLS-1 include 6 cardiovascular/cardiopulmonary investigations, 1 renal/endocrine system investigation, 3 blood system investigations, 6 muscle and bone investigations, and 3 neurovestibular system investigations. Ten of the investigations use crew members as subjects, nine use rodents, and one uses jellyfish.

Some of the investigations manifested on SLS-1 are:

- **An erythrokinetics experiment** designed to study the mechanisms that may affect red blood cell levels during space flight. Erythrokinetics is the study of the production and disappearance of red blood cells (erythrocytes). Researchers have already learned that space flight causes a decrease in circulating red blood cells, which reduces the oxygen-carrying capacity of the blood and may temporarily decrease a crew member's ability to function with full efficiency upon return to Earth. This experiment will also address the effect of space flight on the rate of red blood cell production and the effect of changes in body weight and plasma volume, which decrease during flight, on red blood cell production. The role of the hormone erythropoietin — which stimulates red blood cell formation — and erythropoietin inhibitors on the reduction of circulating red blood cells and the possible role of shortened red

blood cell life in the reduction of red cell mass will be studied. Crew members will be injected with a tracer to measure iron metabolism; blood samples will be collected to study the rate at which iron is incorporated in red blood cells.

- **A bone mineral loss experiment** intended to measure changes in circulating levels of calcium metabolizing hormones and the uptake and release of calcium in the body that occur during space flight. Changes in calcium homeostasis, or the balance of calcium entering and leaving the body, have been observed in previous space flights. These changes are similar to the osteoporosis observed in humans subjected to immobilization. Osteoporosis is a condition in which bone mass decreases and the bones become porous, brittle, and prone to fracture. Because this condition could cause health problems for astronauts returning to Earth after long stays in space, the mechanisms behind calcium homeostasis are of great interest in space medicine.

- **An investigation of protein metabolism** in space. Astronauts consistently experience a decrease in muscle size, strength, and protein content during space flight. These changes could be due to a decrease in protein synthesis or an increase in protein breakdown. The objective of this experiment is to determine the mechanisms involved in the altered protein metabolism, including changes in protein synthesis rates, muscle breakdown rates, and use of dietary nitrogen. Blood and urine samples taken from crew members will be analyzed to measure the uptake of a chemical tracer by muscles as they are forming new protein. Each crew member will be weighed daily, and a log will be kept of all food, fluids, and medication ingested to aid in determining total nitrogen balance (nitrogen is a primary constituent of protein).

- **An analysis of pulmonary function** in weightlessness. Gravity plays a major role in various aspects of pulmonary function, including ventilation and blood flow. The lungs are anatomically distorted by gravitational loading (mechanical stress due to the weight of the lung and rib cage). Gravity also affects the major function of the lung — gas exchange, or the movement of oxygen from air into blood and of carbon dioxide out of blood. SLS-1 crew members will perform a series of eight pulmonary function tests before, during, and after flight. Inhaled and exhaled gases will be analyzed.

- **An experiment intended to determine the mechanisms and time course of cardiovascular adaptation** to weightlessness. Combined data from previous space flights suggest that the heart and blood vessels adapt to weightlessness rapidly and effectively; signs of major dysfunction appear only upon return to normal gravity. The hypothesis to be tested in this experiment is that the adaptation is primarily a response of the cardiovascular system to a rapid headward shift of body fluids upon entry into microgravity. The primary objectives of this experiment are to investigate the acute changes in cardiovascular function, heart dimensions and function at rest, cardiovascular response to maximal exercise, and control mechanisms of the cardiovascular system. An echocardiograph, which outlines the major internal organs by bouncing high-frequency sound waves off them, will be used to image the functioning heart on a video screen in real time. An apparatus called a venous occlusion cuff will be used to block veins of the leg artificially and measure resulting blood flow, and a bicycle ergometer will be used to measure cardiac output and related factors during maximal exercise routines.

In addition to biomedical investigations, the SLS-1 payload includes several items of life sciences laboratory equipment that will undergo flight verification testing: the Small Mass Measuring Instrument (SMMI), Refrigerator/Incubator Module (RIM), General Purpose Work Station (GPWS), and General Purpose Transfer Unit (GPTU). A surgical work station designed for the Health Maintenance Facility (HMF) that will be installed on Space Station Freedom will be tested on SLS-1.

A joint U.S.-U.S.S.R. biospecimen sharing plan is part of the SLS-1 mission. Tissue samples from rats flown for SLS-1 experiments will be shipped to Soviet biomedical researchers. In return, U.S. researchers will receive tissue samples from animals flown on Soviet Cosmos biosatellite missions.

The crew of SLS-1 includes:

- Commander Brian O'Connor, pilot Sidney Gutierrez, and mission specialist Tamara Jernigan.
- Two mission specialists with shuttle flight experience who will participate in flight experiments — M. Rhea Seddon, M.D., and James P. Bagian, M.D.
- Two private-sector payload specialists, chosen by principal investigators to represent them on the mission — F. Andrew Gaffney, M.D., a cardiologist with the University of Texas Health Science Center in Dallas; and Millie Hughes-Fulford, Ph.D., a cell biologist at the Veterans Administration Medical Center in San Francisco, California.

Full-time crew training for SLS-1 began in the spring of 1989. An experiment verification test (EVT) — a “dry run” intended to simulate preflight, flight, and postflight science operations on the ground for the actual duration of the mission — was successfully completed at the Ames Research Center in early 1989, with payload crew members participating. In 1989, planning advanced for the SLS-1 follow-on mission SLS-2, which will repeat most of the experiments on SLS-1 to verify and expand upon results. The payload manifest for SLS-2 was finalized in late 1989.

Physiological changes during extravehicular activity are under study.

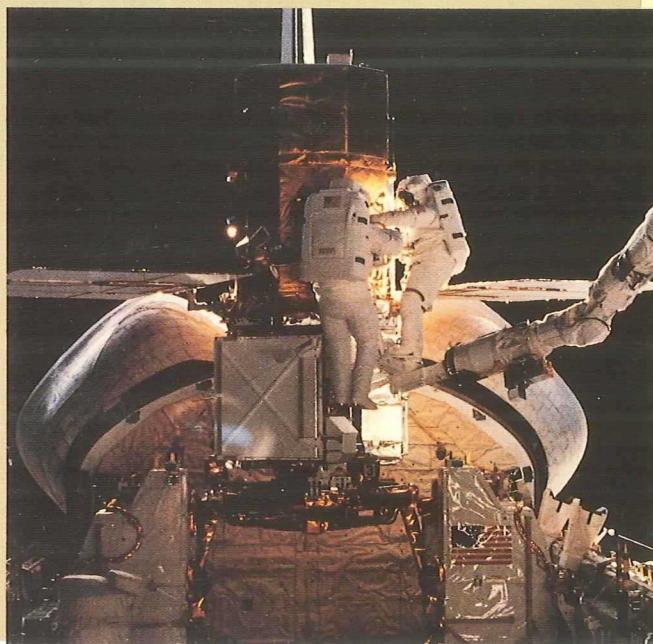
Extravehicular Activity

The formation of air bubbles in the blood vessels of crew members during Space Shuttle or Space Station extravehicular activity is a problem targeted for study by NASA biomedical researchers. Crew members must adjust from spacecraft cabin pressure to space suit pressure before EVA, and the decompression process causes the release of air bubbles into certain tissues and the circulatory system. Bubbles circulating through the lungs normally are eliminated by diffusion of the gas. But if excessive quantities of venous bubbles are present, the lungs cannot filter all of them out, posing a risk of arterial air embolism. Researchers are exploring the ability of the lungs to filter out excess gas bubbles, damage that could be done by bubbles on the lungs, the length of time that constitutes a safe interval between successive decompressions, and the effects of decompression bubbles on work performance and physiological well-being.

Radiation Exposure

Before humans embark upon long-duration space missions, scientists must learn more about the biological effects of space radiation and improve evaluations of radiation-induced risks to space crew members. Subjects

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requiring further study include molecular-level mechanisms involved in radiation-induced cell transformation and the relationship between mutations and lethal damage caused by radiation.

1989 Activities and Accomplishments

In 1989, the Life Sciences Division drafted a **radiation research program plan** to address these needs. The Life Sciences Division is now sponsoring some preliminary radiation research projects.

Cosmic radiation exposure is not a risk for crew members in the low-Earth orbit of the Space Shuttle. Because of the protective effect of Earth's magnetic field and the low-altitude, low-inclination orbit planned for Space Station Freedom, radiation levels should be acceptable on Freedom, according to a recent study done by the National Council on Radiation Protection and Measurements. In 1989, the NCRP completed guidelines on human exposure to space radiation — one-time exposures on a single space mission and career exposures over multiple missions. The guidelines include exposure limits for eyes, skin, and blood-forming organs. The NCRP is also involved in ongoing evaluations of space radiation hazards.

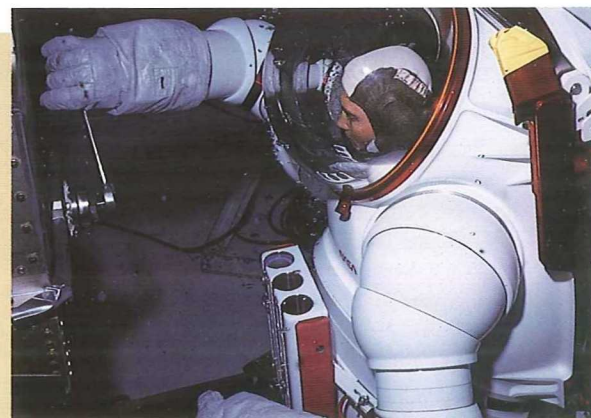
It is on long-duration human solar system exploration missions that exposure to cosmic radiation may be a problem. Space Shuttle missions already are being used to collect data on radiation exposure and shielding requirements. A NASA-sponsored research team has been measuring heavy-ion (HZE) radiation on Space Shuttle missions with passive dosimeters worn by crew members and placed around the cabin. In addition, joint **U.S.-U.S.S.R. radiation dosimetry experiments were flown on Cosmos biosatellite missions in 1987 and 1989.**

Experimental data on the molecular mechanisms of cell transformation by radiation are needed to understand the biological effects of radiation and to develop biophysical models that can help to determine

dose-response curves at low doses.

Researchers have already learned that ionizing radiation can cause cell transformation directly and that high-linear-energy-transfer (LET) heavy ions can be more effective than photons (x-rays) in transforming and killing cells. But they do not yet know much about the molecular nature of radiation-induced lesions that contribute to cell transformation, the relationship between transformational and lethal damage, and the evolution of initial damage into chromosomal aberrations that alter cell growth. DNA has been shown to be the primary target in cell transformation by radiation. Space radiation researchers have determined that the high relative biological effectiveness (RBE) of high-LET radiation in mutating and killing cells is most likely related to its effectiveness in producing DNA double-strand breaks.

Radiation physicists have been studying interactions of galactic heavy ions such as those present in cosmic radiation. Outside of Earth's magnetic field, these particles and the products of their nuclear interactions with spacecraft materials and human tissue are second only to solar flares as a major space radiation hazard. In the BEVALAC nuclear accelerator at Lawrence Berkeley Laboratory in California, atomic nuclei similar to those encountered in space are shot at high speed into target samples of spacecraft materials and human tissue equivalents. These experiments are yielding information on the biological effects of radiation encountered in space.



Testing new space suit designs.

Future Activities

Meanwhile, theoreticians are working on models of HZE particle interaction and transport to be used in determining space radiation shielding requirements for future long-duration human missions. Likely components include hydrogen-rich materials such as water. Investigators have already begun defining radiation background and shielding requirements for a lunar base and a human mission to Mars.

In the near future, additional radiation dosimetry experiments may be flown on the U.S.S.R.'s space station Mir and on future Shuttle missions.

Technology Development

Some new instruments are under development to collect dosimetry data in space. Special spectrometers will measure the distribution of energy in small volumes of biological material. And a small, battery-powered electronic data acquisition system, to be used with a proton/heavy ion dosimetry detector being developed at Johnson Space Center, will collect preliminary data on the distribution of high-linear-energy-transfer (LET) events produced by secondary particles; these particles are generated by collisions between cosmic radiation particles and atoms that make up the spacecraft and its crew.

Human Factors and Performance Research

NASA's human factors and performance research program aims to understand crew members' capabilities and limitations in space, collect quantitative data on performance, and integrate such data into models that can predict performance in space. These objectives are of primary importance in expanding human presence beyond Earth orbit. By collecting data through ground-based studies and using the data to form theories of human performance and develop equipment for

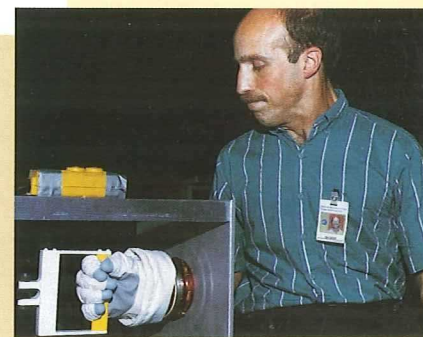
space-based studies, researchers can help to improve the design of spacecraft and the understanding of human performance capabilities and limitations. Studies are conducted in ground-based laboratories, KC-135 aircraft, and JSC's Wet Environment Training Facility (WETF — a neutral buoyancy tank).

Human performance research at NASA has three major thrusts: collection of anthropometric and biomechanical data in microgravity and simulated microgravity; development of predictive models to portray the physical capabilities of crew members in action through computer analysis and animation; and organization of data in a form accessible to designers and operations planners.

1989 Activities and Accomplishments

In the area of human performance **researchers conducted instrumented treadmill locomotion studies with human subjects in Earth gravity, partial gravity, and microgravity (on KC-135 flights) in 1989**, to begin assessing requirements for lunar and martian EVA space suits and for space station exercise countermeasures to physiological deconditioning. They also collected metabolic data on space-suited crew members in Earth gravity and neutral buoyancy.

Space suit testing in the WETF and KC-135 has shown that a complex interaction between the nature and direction of motion and the suit itself may increase or decrease the production of force in different circumstances. Planning for extravehicular activity by crew members on Space Station Freedom requires high-fidelity models of three NASA space suit models — the Space Shuttle suit now in use and two prototype high-pressure space station suits (the AX-5 and Mark III). **Through a new initiative begun in 1989**, researchers will develop **human factors models for all three suits** with very accurate representations of size, shape, joint limits, and resistance.



Astronaut James Bagian tests a space suit glove.

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JSC's Human-Computer Interaction Laboratory supports the development of advanced human-computer interfaces for spacecraft and has already assisted space station planners in upgrading the Human-Computer Interface Guide prepared for Space Station Freedom operations. Researchers at the lab have been comparing graphic and textual displays of information to be provided to crew members by computers, and upcoming research will look into the effectiveness of pictographic icons, detailed pictures, and maps for the display of data. The use of different types of screen coding — blinking or color coding, for example — to aid in the performance of search/identification tasks will also be studied.

Future Activities

One of the tools used by JSC human performance researchers is a group of related computer models and databases unified by a framework of geometrical calculations and computer graphics. Called PLAID, this tool provides a three-dimensional geometrical representation of spacecraft and objects in them, including human forms, which is useful for analyzing and animating dynamic processes.

A human reasoning research initiative is being developed, in which investigators will identify and analyze space tasks that require reasoning and decision-making, develop tools for analyzing operator reasoning and problem solving, and then develop decision-support aids for use in a complex space-based task. This research will improve the productivity of crew

members in orbit and advance understanding of the human reasoning process.

Technology Development

Researchers are also developing new equipment and methods for collecting quantitative data on performance. **In 1989, a biomechanics integrated measurement system developed by JSC researchers became operational.** The system includes a three-dimensional tracking feature and a dynamometer to measure force. Researchers collected data on the performance of astronauts in shirt sleeves and in new prototype space suits being developed for Space Station Freedom. Infrared telemetry of electromyograph data — information on electrical activity in muscles — was also tested.

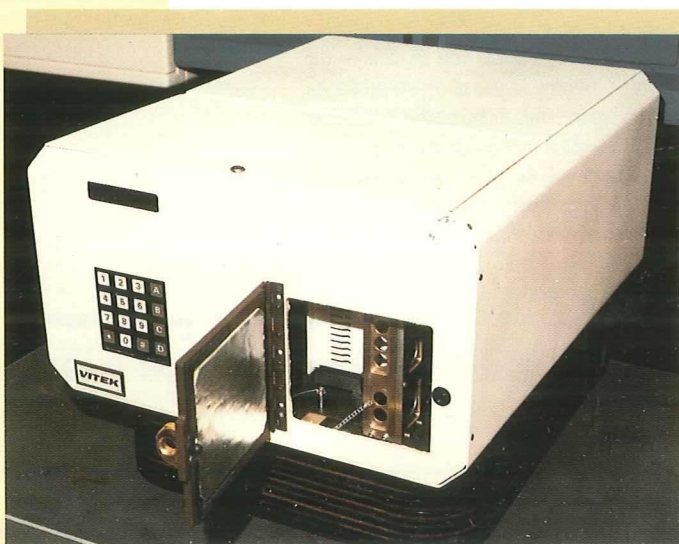
A new laser-based anthropometric mapping system (LAMS), developed to collect data for three-dimensional maps of the human body, **was set up and checked out in 1989.** Next year, the system will be used to collect data from several subjects, and the data will be formatted to provide body models. The LAMS will be used for Earth-based investigations, but ultimately it will be scaled down for operation in space. Data collected by the LAMS will be used to accurately determine key body size parameters such as arm length, height, and girth, needed for designing such items as spacecraft seat size and position and the location of restraints.

Designing Gloves for Space Suits

Space suit gloves have always been a source of trouble for astronauts working in space. During extravehicular activity, when time is especially valuable, gloves commonly cause pain and numbness that may make it difficult for an astronaut to complete a task and may last for days or even weeks after flight. Space-based assembly of Space Station Freedom will require intensive EVA on the part of many crew members, and as part of NASA's efforts to prepare for the job, EVA gloves are under evaluation in the human factors research program at JSC.

NASA's Automated Microbiology System.

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Researchers have interviewed developers and users of EVA gloves and found that dexterity, tactility, and comfort are the biggest problems experienced in the use of the gloves. These factors are also hard to measure. Non-intrusive instrumentation will be developed for collecting data on gloves during actual EVA on Space Shuttle missions. Performance requirements for EVA gloves eventually will be developed, and new gloves will be fabricated to test them.

One means of improving EVA glove design now under investigation at JSC is the use of a laser scanning technique to make detailed digital images of hands and gloves. This method is far more accurate than physical measurement in producing critical hand anthropometric dimensions. NASA's current method of designing gloves requires individual physical measurements of hand case molds, a method highly subject to error. More accurate data produced by hand contour mapping with the laser scan will permit more accurate fabrication of gloves. These improved measurements will also make it easier to alter or adjust sizing and mobility features for individual crew members, reducing glove fabrication time.

In 1989, researchers will develop a critical hand anthropometric data base; in 1990, they plan to assemble a new prototype glove and conduct crew member fit checks and performance evaluations.

Environmental Controls

Life scientists are studying ways to monitor air and water quality in spacecraft environments as well as microbial and chemical contamination.

For example, biofilm — an accumulation of bacteria on a surface — is a potential problem for spacecraft water supply systems. At most, bacterial contamination of water supplies on Space Station Freedom could be pathogenic or toxic; at minimum, it could affect the taste of water and consequently reduce crew water intake.

1989 Activities and Accomplishments

An Automated Microbiology System (AMS-II) being developed for Space Station Freedom will provide infectious disease diagnostic support and therapy information and microbial identification and quantitation data with particular emphasis on the microbial quality of air and recycled water. About the size of a laser printer, the AMS-II will analyze samples from crew members and their environment, electronically detecting microbially induced chemical reactions and growth in test wells.

The system will be able to process 10 isolated microbe species simultaneously and accommodate new samples every 12 hours; most "bugs" that may be present in a spacecraft environment will grow in the sampling container within eight hours. The AMS-II is an upgraded, downsized version of a system used widely in hospitals and industry; the space-station-rated system could have broad ground-based applications as well.

Future Activities

JSC has established an Environmental Health System Project to develop monitoring equipment for Space Station Freedom that is lightweight, reliable, highly automated, and low-maintenance. Toxicology, microbiology, water quality, radiological health, vibroacoustics, and barothermal physiology will be addressed during the course of the project. In some cases, commercially available equipment will be modified for space flight; in other cases, new equipment will be developed.

Technology Development

To study the long-term potential of biofilm development and evaluate iodine as an antimicrobial agent, **JSC began operating a testbed in 1989 that simulates a spacecraft water system.** In addition, a volatile organic analyzer is being developed for spacecraft air quality monitoring. The compact device will sample air in an automated mode, saving crew time for more substantive tasks.



GRAVITY, LIFE, AND SPACE

THE SPACE
BIOLOGY
PROGRAM

All life on Earth has evolved in the presence of gravity, and gravity therefore plays an integral role in all life processes. Gravity influences the morphology, physiology, and behavior of life in virtually all of its manifestations. The goals of the Space Biology Program are to understand how gravity affects plants and animals, determine the effects of the interaction of gravity and other environmental stresses on biological systems, and improve the quality of life on Earth by advancing knowledge in the biological sciences. What space biology researchers are learning about how living organisms perceive and respond to gravity and adapt to microgravity is making a significant contribution to the understanding of life.

Research sponsored by the Space Biology Program is intended to study and define the role of gravity in life by addressing questions such as: How do plant cells detect gravity and translate the force into neural, hormonal, or other physiological signals? Can plants and animals reproduce over several generations in microgravity? What is the relative contribution of gravity to sensorimotor function? What fundamental biochemical and physical processes govern bone formation and resorption?

By examining animal development in space, researchers can address the fundamental role that gravity plays in the process, as well as the biophysical, biochemical and biological mechanisms involved in directing the shape and behavior of organisms and the development and functional competence of gravity-sensitive organs. By studying the role of gravity in skeletal growth and development, for example, researchers are attempting to

determine what turns bone-forming (osteoblast) and bone-resorbing (osteoclast) cells on and off and whether and how these cells communicate with each other and with their environment.

Bone and Muscle Research

Bone is a dynamic, living tissue and continually undergoes change, or remodeling, which involves a delicate balance between bone formation and bone resorption. This balance is influenced by hormones, vitamin D, and other factors such as blood flow. Space biology research aims to explain the role that hormones play in coupling the mechanical stress of weight bearing to the cellular activity of bone formation. A NASA investigation flown on the Soviet Cosmos 1887 biosatellite mission in 1987 (*see p. 39*) showed that space flight can damage blood vessels in some weight-bearing bones.

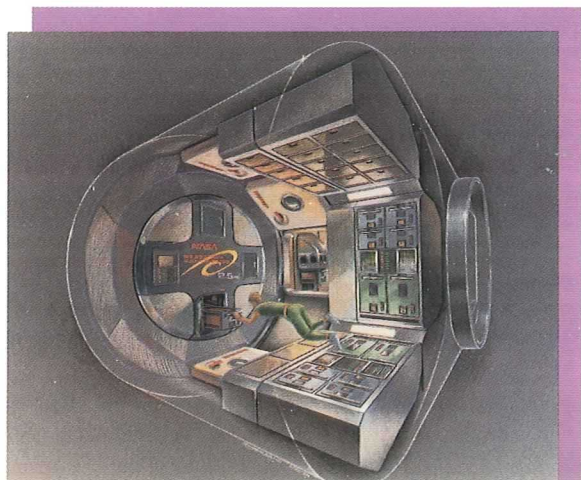
Weight-bearing bones lose mass during space flight. Researchers suspect that glucocorticoids - steroid hormones that accelerate the conversion of protein (muscle tissue) to glucose (blood sugar) - may play a role in bone loss during space flight.

1989 Activities and Accomplishments

Patients treated on the ground with the synthetic glucocorticoid prednisone show reduced bone formation, probably because the medication directly inhibits the function of bone-forming cells. In ground-based experiments, researchers attempting to identify the cause of glucocorticoid-induced bone loss have verified that elevated concentrations of glucocorticoids inhibit the functioning of osteoblasts and the synthesis of the collagen matrix required for bone formation and mineralization.

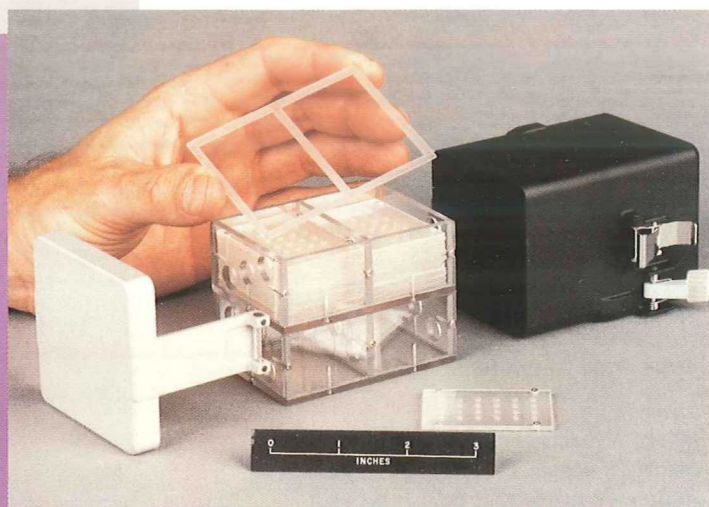
Growth hormone is required not only for bone growth but also for fat and carbohydrate metabolism and proper immune system functioning. It may also play a role in wound healing, kidney cell function, and muscle

Experiments on Space Station Freedom will help define the role of gravity in life.



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metabolism. Since many of these growth hormone targets are affected by space flight, researchers are attempting to determine how space flight affects the release of growth hormone by the pituitary gland. Three space experiments, two on the Space Shuttle and one on a Soviet biosatellite, have used pituitary cells in culture to measure growth hormone output before and after flight. Results show that the cells released 50 percent less growth hormone after flight than they did before. These results are preliminary, and these experiments must be repeated in flight before firm conclusions can be reached.

The recent discovery of the immunoregulatory effects of vitamin D in the body suggest that bone metabolism and mineral homeostasis may interact with the immune system through vitamin D. One group of researchers has postulated that changes in bone metabolism induced by microgravity decrease circulating levels of vitamin D, required for normal function of the immune system, brain, bone, vestibular system, pancreas, and pituitary; reduced levels of vitamin D lead to depressed immune cell activity. Researchers are also attempting to delineate the electrical-chemical pathways through the brain that mediate gravitational and stress-induced changes in the production of renin and other salt- and water-regulating hormones. Postural changes and stressful stimuli increase renin production, and renin plays a vital role in salt and water balance and the maintenance of blood pressure.

Circadian (daily) rhythms may also be affected by exposure to the microgravity environment of space. Scientists are interested in determining whether circadian rhythms are

A Space Shuttle middeck experiment will study circadian rhythms in Neurospora.

controlled by external cyclical influences such as sunlight or by internal mechanisms. A middeck experiment was scheduled to fly on STS 32 in late 1989 to characterize how exposure to microgravity affects circadian rhythms in a fungus (*Neurospora crassa*).

Future Activities

Another investigation aims to describe the mechanisms by which calcium ions and calcium-mediated physiologic mechanisms interact with gravity during inactivity. The intent is to determine how exercise after prolonged muscle atrophy affects skeletal muscle and, more specifically, to identify atrophy-associated cellular changes that might lead to skeletal muscle injury during recovery. Laboratory studies have shown that exercising atrophied skeletal muscles following inactivity can damage myofibrillar tissue (contractile fibers in the muscles). Simple weight bearing, if suddenly initiated following atrophy, may be enough to injure the atrophied muscles after only 28 days of inactivity.

Plant Research

Plant research in the Space Biology Program delves into a broad array of subjects, such as cell metabolism and structure, cell division, intracellular versus extracellular effects, genetic expression and differentiation, genetic mutation and recombination, fertility and fecundity, gravitropism, and gravity interactions with light, vibration, and magnetic charge. Understanding how plant growth, physiology, and development are affected by gravity and how gravity interacts with other environmental factors affecting plants should provide new insights into plant growth.

1989 Activities and Accomplishments

Investigations sponsored by the Space Biology Program focus on such aspects of plant growth as the light modulation of gravitropism; the role of calcium in mediating cellular functions; and the role of calcium, hormones, and light in the regulation of growth. One hypothesis to be tested proposes that plants respond to all

mechanical forces, including gravity, by means of similar cellular mechanisms. Investigations aimed at testing this hypothesis could contribute significantly to the understanding of stress reactions in plants.

The biochemical and physiological processes by which plants regulate growth in response to altered gravity are poorly understood. Understanding such mechanisms will improve scientific prediction of plant growth responses in Earth gravity and in microgravity environments. One NASA-sponsored investigation has already shown that gravity affects the structure and function of plant cells. For example, plants grown in microgravity appear to contain much less starch than those grown on Earth. If long-term studies bear out this preliminary observation, then developers of bioregenerative life support systems must take into account that starch-rich plants, such as wheat, grown in space may have a lower caloric content than plants grown on Earth.

Plant growth chemicals made in shoot and root tips, called **auxins**, are the subject of current **space biology investigations**. Researchers are studying the auxin indole-3-acetic acid (IAA), along with calcium, toward developing a theory of the transduction of the gravitational stimulus in plants. One research team is studying the possibility that phosphorylating enzymes play a role in transducing the gravity stimulus. Creating a gravitational stimulus - for instance, changing a plant's orientation with regard to the direction of gravitational force - will induce an asymmetric distribution of IAA and calcium that prompts plants to change their direction of growth in keeping with the direction of gravitational force. Identifying the mechanism by which this chemical asymmetry is attained could yield an understanding of the gravity response at the molecular level. One group of NASA researchers has proposed that the target of the gravity stimulus in plants is the gates within the plasmodesmata (cytoplasm connecting adjacent plant cells) that control the movement of IAA from the vascular stele (water and nutrient conduits) into surrounding plant tissue.

Cell division rates, chromosomal integrity, patterns of differentiation, and even cell shapes appear to be affected by space flight. Disturbances in the process of cell division, indicated by a variety of chromosomal abnormalities, are thought to be attributed to events regulated by calcium. Carbohydrates have been depleted consistently in roots and leaves of plants grown under weightless conditions. Specialized cell parts called organelles that provide complex carbohydrates such as cellulose to maintain cell wall integrity in plants are decreased 10 to 50 percent during space flight, resulting in a thinning of the walls.

Further, levels of cellulose, lignin, and the enzymes of lignin biosynthesis have all been reduced in space investigations, indicating that plant structural organs are affected at the molecular level. An understanding of the biological mechanisms involved in the development and physiological changes observed in plants grown in space will contribute to the development of controlled ecological life support systems for space missions. In addition, such an understanding has strong potential for diverse economic benefits on Earth, particularly in the areas of plant culturing and agriculture.



CHROMEX plant roots grew in different directions in the absence of gravity.

LifeSat will carry biology and radiation experiments into space.

Space Biology in Orbit: CHROMEX

On March 13, 1989, the Space Biology Program went into orbit aboard Space Shuttle mission STS 29 with the **launch of a chromosome and plant cell division experiment called CHROMEX**. This dual-purpose experiment was intended to test biotechnology capabilities by growing plants from cloned cell cultures rather than seeds, and to evaluate the effect of microgravity on cells crucial to the normal development of plant root tips.

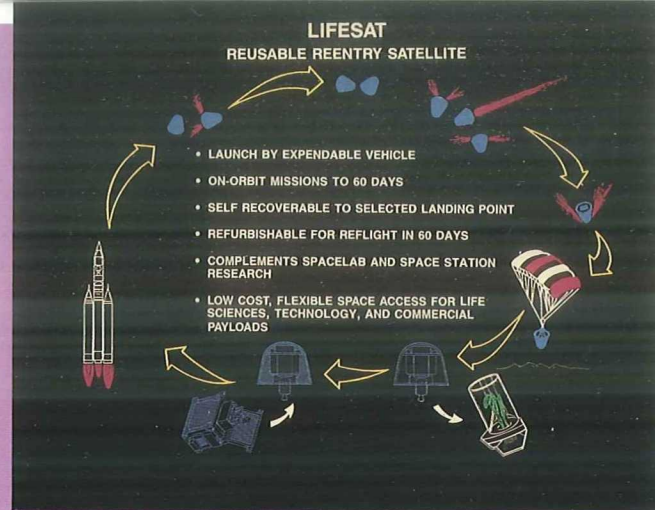
The two species of plants used for this experiment were *Haplopappus gracilis* (a daylily) and *Hemerocallis* (a member of the aster family). The experiment was housed in a plant growth unit that could provide a controlled environment and be stowed in a mid-deck locker. Before launch, the roots of CHROMEX plant specimens were trimmed. In space, the plants grew new root tips that were analyzed after flight for any abnormalities.

Past observations have indicated that some plants grown in space show chromosomal abnormalities and a reduced level of cell division in root tips. Preliminary results of the CHROMEX experiment indicate that root-tip-cell chromosomes were damaged during space flight and that the damage was greater than that attributable to space radiation exposure alone. Microgravity or some other feature of the space environment may combine with radiation exposure to alter the cell division process.

CHROMEX was the first Space Shuttle payload to be fully developed at Kennedy Space Center.

Future Activities

In 1989, NASA initiated two design studies for a recoverable reentry biological satellite called **LifeSat**, outfitted to accommodate plants and small animals. Interdisciplinary LifeSat



missions will significantly expand NASA's capability to study how living organisms respond to weightlessness and cosmic radiation. LifeSat and other recoverable reentry satellite (RRS) missions will fly on expendable launch vehicles, reserving the Space Shuttle for activities requiring crew presence. The RRS may also be outfitted for microgravity science experiments.

The two major advantages of flying life science investigations on LifeSat missions are longer-duration flights of 30-60 days and operations in higher orbits than the Space Shuttle, where cosmic radiation is a factor. With timelines for human missions into space growing longer and destinations moving further away from Earth, life scientists need to learn more about how the radiation environment of deep space will affect living organisms on long-duration missions. They also need to examine microgravity-induced changes that worsen or only become apparent during space missions longer than a Shuttle flight. On extended-duration Shuttle missions, crew members will be experimenting with microgravity countermeasures and therefore will not be able to provide information on the effects of uninterrupted extended exposure to the microgravity environment.

Rodent, Plant, and General Biology Modules will be developed for LifeSat experiments. In addition to NASA, five foreign space agencies are expected to participate in LifeSat missions: the European Space Agency, the National Space Development Agency of Japan (NASDA), the German Aerospace Research Establishment (DLR), France's Center for National Space Studies (CNES), and the Canadian Space Agency.

LifeSat will be an almost completely reusable spacecraft that could be processed and readied for reflight in two months, allowing several flights each year. The biosatellite will measure approximately six feet in diameter, weigh about 2,000 pounds, and accommodate about 500 pounds of payload.

The Variable Gravity Centrifuge

A Variable Gravity Centrifuge Facility is being developed for plant and animal investigations on Space Station Freedom beginning in the late 1990s. A space-based centrifuge will permit investigations of threshold levels of fractional gravity required to maintain the structure and function of living systems and of intermittent hypergravity as a countermeasure to space adaptation.

The Variable Gravity Centrifuge will spin to create gravity fields ranging from 0.1 g to 2.0 g, including one g, to permit control experiments in space. The centrifuge will not disturb the microgravity environment of Space Station Freedom. The centrifuge facility will include modular habitats for plant and animal specimens, a glovebox for crew members to use in handling specimens, and a specimen chamber service unit. The modular habitats fit into holding units that supply air, power, cooling fluids, waste handling, contamination control, instrumentation, and television links. Instrumentation can measure animal temperature, heart rate, blood flow, activity, and physical condition. The facility will be chemically, biologically, and mechanically isolated from other experiments.

A systems engineering study of the Variable Gravity Centrifuge Project was completed in 1989, and design studies were scheduled to begin in late 1989.

The Space Biology Initiative

In 1989, planning advanced for the Space Biology Initiative (SBI), a space life sciences program that will yield facilities for exobiology, gravitational biology, space physiology, and controlled ecological life support systems (CELSS) research on future Space Shuttle/Spacelab missions and on Space Station Freedom.

Because of the biological variability and the inherent complexity of living systems, life sciences research requires a series of

investigations, each building on the results of preceding ones and probing more deeply to find fundamental answers. The SBI will enable this kind of a series of research, allowing scientists to mount in-depth, highly sensitive and ultimately comprehensive investigations of how biological systems respond to the absence of gravity, honing in on specific biological and physiological processes that are affected by exposure to space.

The SBI encompasses four elements of research that concentrate on changes at molecular, cellular, organismal, and population levels. Gas-grain simulation investigations will enable the study of small-scale physical, chemical, and biophysical processes at a level of resolution never before possible. Gravitational biology investigations will examine the role that gravity has played in shaping the growth and development of cells, plants, and animals. Space physiology investigations will use the space environment to study control mechanisms of biomedical significance. And controlled ecological life support investigations will focus on understanding the effects of gravity on plant productivity, an important step toward developing bioregenerative life support for long-duration space missions.

Generic hardware now available for Spacelab experiments is more than 10 years old and in need of upgrading, not just replacement. The intent of the SBI is to produce a new suite of generic flight hardware based on currently available technology. However, the new equipment will be more efficient, require less power to operate, weigh less and take up less space, cut down on crew time required for tending experiments, and reduce turnaround time and refurbishment costs. SBI equipment will include dozens of items, such as an animal biotelemetry system, blood flow and plethysmography system, cell harvester, second-generation gas analyzer/mass spectrometer, and plant gas chromatograph/mass spectrometer. One major piece of SBI equipment, the Gas-Grain Simulation Facility (GGSF), will support exobiology investigations of particle-particle and gas-particle interactions in a microgravity environment



SUSTENANCE IN SPACE

CONTROLLED ECOLOGICAL LIFE SUPPORT SYSTEMS PROGRAM

As human exploration missions in space grow longer, controlled ecological life support systems (CELSS) may be required. Regular resupply of air and food constitutes a major factor in the cost of operating space stations, lunar bases, and missions to Mars. Researchers are studying bioregenerative life support techniques based upon plant photosynthesis that can provide food, potable water, and breathable air without major and constant resupply from Earth.

1989 Activities and Accomplishments

Ground-based research continues at the Kennedy Space Center's CELSS Breadboard Project. In the Breadboard's Biomass Production Chamber, 34 different sensors measure 10 different environmental parameters in various parts of the chamber, every four minutes. Wheat has been grown in 16 square meters of growing area; **in the fall of 1989, soybeans were planted in the chamber.** The nutrient film technique is now used for nutrient delivery in the chamber, but KSC is testing different hydrophilic porous materials, such as porous polyethylene tubes and cylindrical porous ceramic filters, for a tubular membrane system that could increase the durability of plant growth units. Development of the CELSS Breadboard should be complete in 1992, and by 1993 researchers expect to demonstrate that the facility can produce enough food and recycle enough air, water, and waste to support the equivalent of one person for one year.

In addition to studying environmental controls and biomass production, researchers now

want to begin working on biomass conversion—that is, processing inedible plant material into food products. Wheat, for example, contains 60-65 percent inedible biomass; that inedible portion consists of 25-40 percent cellulose, 25-50 percent hemicellulose, and 10-30 percent lignin. Humans lack the enzymes required to digest these fibers, but many microorganisms produce such enzymes and could be used to convert inedible biomass into food products.

This year, three enzymes produced by microorganisms will be tested for their efficiency in breaking down inedible biomass from crops grown in the Biomass Production Chamber.

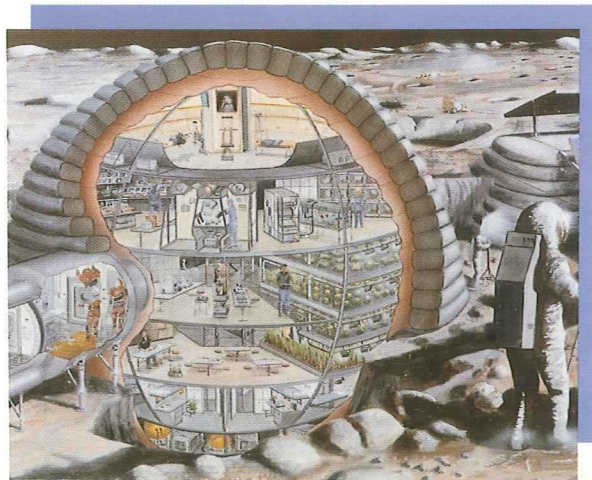
One ground-based CELSS research project sponsored by NASA uses three types of controlled environment chambers to study wheat production. The growth cycle of wheat was cut in half (from 120 to 59 days) in an initial experiment by regulating temperature and light. The yield was double the world record for field agriculture (24 versus 12 grams of wheat per square meter per day). However, edible biomass totalled only 24 percent of total plant mass, compared to 45 percent in the field.

In a subsequent experiment, temperature was lowered somewhat, the dark period in a 24-hour cycle was shortened, and planting density was increased. The result was a yield of five times the world record in the field (60 grams per square meter per day) with a 79-day growth cycle (compared to 120 days in the field). The conclusion is that the yield and efficiency are strong functions of the daily dose of light.

Meanwhile, at Johnson Space Center, CELSS researchers are studying the viability of lunar-derived soils for plant growth at lunar bases. Unaltered lunar regolith, a synthetic, highly productive solid-support substrate, and lunar simulants are under consideration.



Food crops such as soybeans are being evaluated for space-based gardens.



Controlled ecological life support systems may be required for bases on the Moon and Mars.

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Future Activities

In 1989, a **CELSS flight program plan** was prepared, identifying flight projects to be launched on Space Shuttle missions and on Space Station Freedom. The initial project, called Flight Early Access: Science and Technology (FEAST), is intended to develop progressively more advanced controlled ecological life support system techniques. FEAST includes **four Space Shuttle investigations that will evaluate how microgravity affects the operation of subsystems and crop plants** to be flown on Space Station Freedom.

CELSS investigations on the Shuttle will cultivate a variety of candidate crop plants; evaluate nutrient delivery subsystems design concepts; study gas/liquid interactions and handling; and evaluate methods of condensing, collecting and reusing water transpired by plants in microgravity. These investigations should be ready to fly in the mid-1990s.

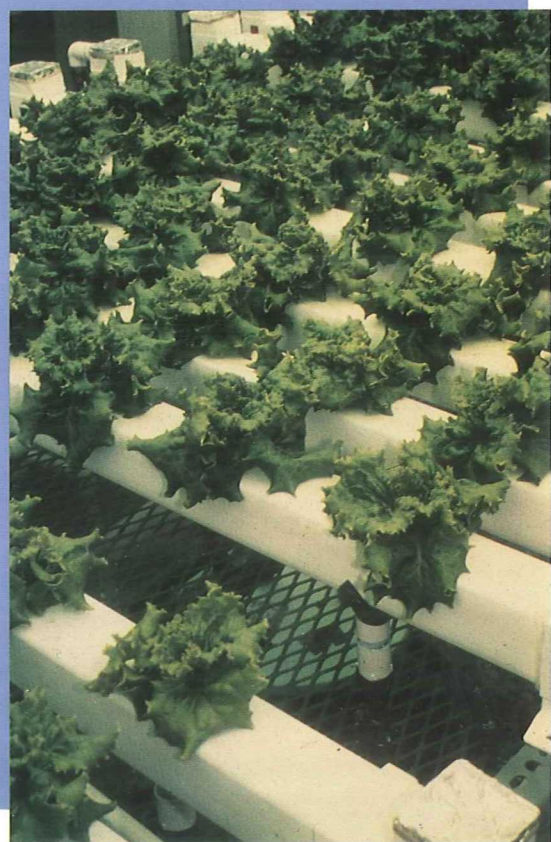
At the Ames Research Center, researchers are designing a **ground-based Crop Growth Research Chamber (CGRC)** as part of a **future laboratory-scale CELSS system**. The CGRC will provide about two square meters of growing area and two cubic meters of growing volume. The facility will be a closed environment offering greater control of factors such as lighting and nutrient delivery than available elsewhere. Fabrication will begin in early 1990.

Technology Development

The results of FEAST investigations will be used to develop a CELSS Test Facility for crop plant growth experiments on Freedom. Hardware for CELSS experiments on the Shuttle and on Freedom will be developed as part of the Space Biology Initiative (*see p. 25*).

Even in non-bioregenerative life support systems, CELSS technologies have important applications such as toxic waste disposal and hydroponic greenhouse plant production. A CELSS applications project being developed for flight at Ames Research Center is the "salad machine," which could yield enough fresh produce to feed a crew of four using a very small volume of space—five cubic meters, the volume of a standard space station rack. The system would be almost totally automated, using germinated-seed cassettes; plants would grow on shelves, and nutrients would be delivered by membranes. This system could be used on Space Station Freedom, at a lunar base, and on human missions to Mars.

Light, nutrients, moisture, and other factors are carefully regulated in CELSS experiments.



Lettuce is a candidate food crop for Space Station Freedom, lunar bases, and missions to Mars.

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LIFE AND PLANET EARTH

BIOSPHERIC RESEARCH PROGRAM

For over three billion years, life on Earth has influenced and been influenced by the planet's atmosphere, hydrosphere, and geosphere. NASA's Biospheric Research Program focuses on understanding how biological processes affect planetary properties. It is devoted to understanding our planet as an integrated biogeochemical system of air, water, land, and life.

The goal of the Mission to Planet Earth now under consideration at NASA is to study our planet as an integrated system undergoing change due to human activity. The Biospheric Research Program can play a role in this effort by determining the role of the biosphere in this complex physical and chemical system. The program examines how biological and planetary processes interact, and how, in conjunction with the environmental effects of human activity, these processes are affecting the long-term habitability of Earth.

Essential biological elements such as carbon and nitrogen follow regular cycles in nature that rely on both living and non-living mechanisms. Certain human activities are disturbing the balance of some of these cycles, but precisely how, and how much, is not known. Many of the questions addressed in the Biospheric Research Program relate to these cycles: What are the reactions and fluxes of the biogenic elements carbon, nitrogen, sulfur, and phosphorus? What are the major sedimentation and erosion processes that the biota influence? How productive are the major ecosystems? How do human activities affect the biosphere? Is it possible to incorporate all of the data produced by satellites and Earth-based instrumentation into predictive models of the Earth?


Researchers currently are studying specific ecosystems, such as temperate forests and wetlands, that contribute to the global picture. Existing data bases, remote sensing techniques, and field research are used to create mathematical models that predict biospheric behavior under a given set of perturbations. These models then are integrated with mathematical models of planetary behavior, such as climate models.

The Biospheric Research Program is organized into five projects: wetlands research (presently focused along the Eastern United States), temperate forest research (presently concentrated on Sequoia National Park), tropical forest research (presently represented by the Amazon Ground Experiment), global studies, and global monitoring and disease prediction (presently focused on malaria). The first four projects consider the interaction of biological processes with respect to regional biogeochemical cycling. Investigations include ground gas flux measurements, nutrient transport flux measurements, associated above-ground vegetation or biomass measurements, and modeling. The fifth project comprises the development of a predictive vector-borne-disease model driven by environmental inputs and encompassing spatial and temporal aspects of disease transmission.

Wetlands Research

Wetlands investigations address the production and transport processes that control fluxes of biogenic gases to the troposphere from coastal wetlands and tidal freshwater estuaries. Researchers are using gas measurements to determine the roles of specific wetland plants in gas transport, composition, and fluxes to the troposphere and to study the effects of soil moisture content on biogenic gas transport. They are also **developing models that ultimately will allow the prediction of emissions of biogenic gases** (dimethylsulfide and methane) from wetland vegetation using remote sensing data.

Other scientists are studying methane production and global fluxes of methane. Investigations are in progress to determine the rates of emission of important biogenic gases from a variety of wetland habitats and to understand the relationship between spectral radiance and plant canopy biomass in wetlands. Remote sensing is being investigated as a technique for studying the role of wetland plants in mediating fluxes of gas-phase carbon and sulfur compounds.



Nutrient cycling in a variety of ecosystems such as the Arctic tundra, is under study.

Temperate Forest Research

Nutrient cycling, air pollution, and biomass burning are some of the topics being addressed in the Biospheric Research Program's Temperate Forest Project. **Plant nutrient ratios (carbon to nitrogen, lignin to nitrogen) and nutrient fluxes are under study** to determine potential for nutrient loss.

Studies have been conducted to gauge the effects of air pollution on temperate vegetation. The objective is to detect air pollution effects on temperate conifer forests and coastal sage scrub, using field observations and airborne remote sensing to measure and analyze light reflected by leaf cover. The results of these analyses should indicate how pollutants have altered leaf chemistry, moisture content, or vegetation structure.

The burning of biomass (forests, vegetation, grasslands) is an important global source of environmentally significant atmospheric trace gases, including carbon dioxide, carbon monoxide, nitric oxide (NO), nitrous oxide (N₂O), methane, and hydrocarbons. Biospheric researchers are **planning several experimental controlled burns to quantify trace gas and particulate production**. Also planned are assessments of the effects of global burning on biogenic emissions of nitrogen oxide and nitrous oxide from the soil by measurements taken before and after burning.

Scientists at Ames Research Center are **using remote sensing data to study the global effects of biomass combustion in natural ecosystems**. One objective is to understand variations in the energy radiated into the

atmosphere by a particular area that are attributable to biomass combustion. Visible, infrared, and thermal remote sensing data will be used in this investigation. Researchers will relate variations in radiance to variables such as erosion and nitrogen leaching due to fire, and ultimately they intend to document how fires affect natural ecosystem processes.

Another investigation will use remote sensing data to assess the health of coniferous forests in the western United States. The aim is to characterize stages of disturbance and regrowth in these forests and develop a database of digital advanced very high resolution radiometer (AVHRR) data to allow regional extrapolation of site-specific measurements.

Tropical Forest Research

Biospheric researchers are working to improve the accuracy and utility of estimates of methane and nitrous oxide fluxes from the central Amazon region by studying temporal variability in fluxes. Methane emissions from the Florida Everglades also have been measured. A comprehensive data set from the Florida and Amazon measurements will be used in **a global methane model being prepared at NASA**. Another investigation focuses on the relationship between tropical forest fertility and hydrocarbon production by vegetation. The goal is to establish a geographic perspective on nutrient cycling and trace gas production by studying the relationships between site fertility, biochemical characteristics of trees, and non-methane hydrocarbon production by a range of tropical forest communities.

An investigation of seasonal and area distributions of nitrous oxide flux in tropical forests is intended to improve scientific understanding of the role that nitrous oxide plays in ecosystem-scale and global-scale nitrogen cycling. Assessing the nitrous oxide flux from tropical ecosystems will help to define its role in global atmospheric processes and to predict the potential effect of disturbing these ecosystems. Another investigation uses

Researchers are studying how biomass burning affects the global environment



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remote sensing data to identify specific forest types that exhibit distinct differences in nutrient cycling and trace gas flux.

Global Models

The effects of human activities on global biogeochemical cycling is under study in the Biospheric Research Program. **Investigators are attempting to model sources of observed increases in global production of methane, nitrous oxide, and carbon dioxide** due to changes in ecosystem nutrient cycling. Four linked, large-scale models have been developed: a terrestrial ecosystem model describing carbon and nitrogen cycling in global ecosystems, a soil moisture model that predicts soil saturation and runoff, a trace gas model that predicts flux rates of methane and nitrous oxide, and a drainage basin model that moves water and nutrients through aquatic ecosystems with accompanying nutrient processing and trace gas production. A related investigation aims to develop a global model of the biospheric sources of methane that will be used to predict concentrations of atmospheric methane due to biospheric changes. This model will be coupled to a global atmospheric tracer transport model to analyze the biogeochemical cycling of methane.

Global Monitoring and Disease Prediction

The Biospheric Research Program is sponsoring a project that is using NASA technology to develop a **predictive vector-borne-disease model for malaria**. Worldwide, more than 250 million individuals suffer from malaria. Almost 50 percent of the world's population lives where the disease is not under control, another 18 percent lives in areas where it could recur, and the number of cases is increasing. It is believed that more people may have died from malaria than any other infectious disease, and, to date, no effective vaccine has been developed.

In partnership with various world health organizations, NASA is using airborne and space-based remote sensing technologies to

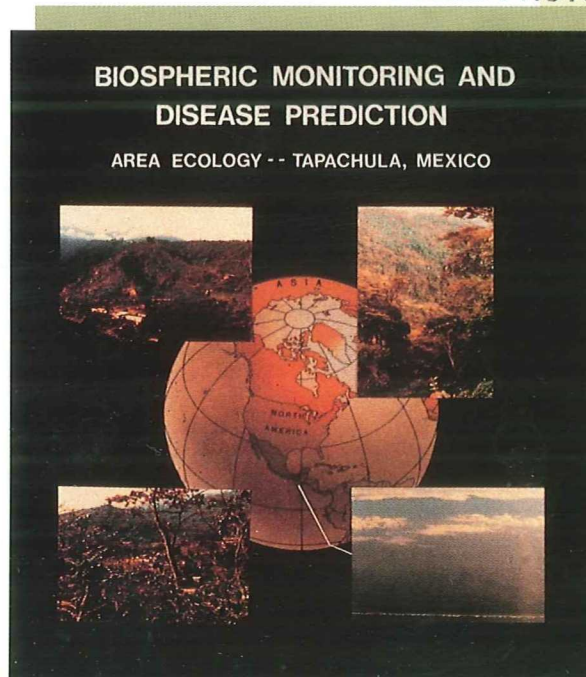
help develop a predictive model for the spread of vector-borne disease. Such a model could identify potential sites of malaria outbreak in order to target control efforts. The technique involves establishing links between the presence of malaria-bearing mosquitos and environmental parameters such as water and vegetation that can be measured by remote sensing. In preliminary studies, NASA-sponsored scientists working in northern California and southern Mexico successfully correlated vegetation stages with the developmental stages of mosquito populations. The goal is to be able to predict the emergence of adult mosquitos.

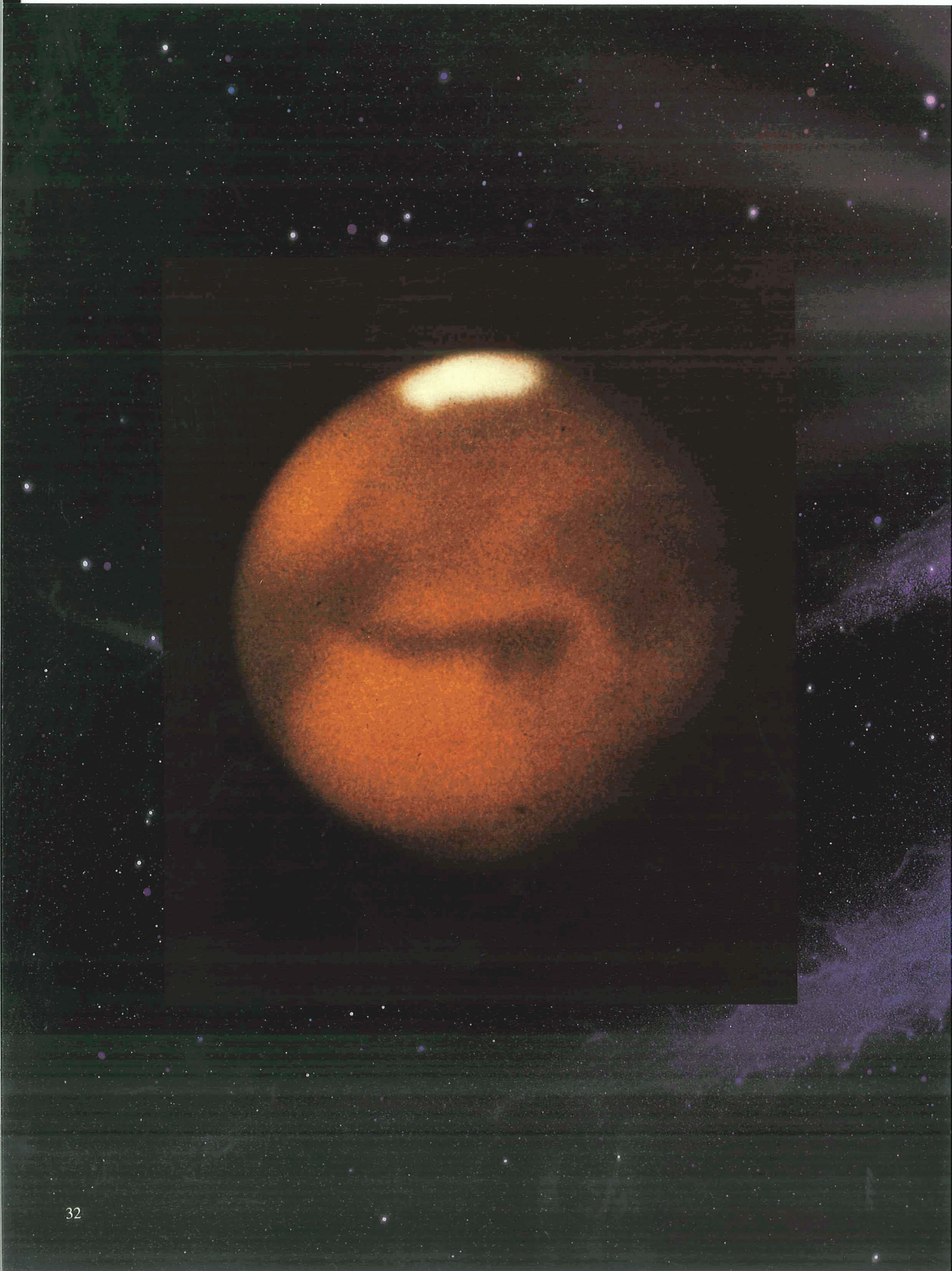
Populations of the malaria-bearing *Anopheles* mosquito rise and fall depending on the availability of suitable habitat, that is, flooded areas that support emergent vegetation. Vegetation growth is largely dependent on water, and remote sensing of vegetation can record different heat "signatures" for plants in different states of growth. In California field studies, scientists have already demonstrated that they can use this technique to predict early in the growing season which rice fields will produce large numbers of *Anopheles* mosquitos later in the season. The research team now is collecting data in Mexico that ultimately will be integrated into a predictive model.



The recovery of burned areas is of interest to scientists studying how biomass burning affects the environment

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LIFE IN THE UNIVERSE

EXO BIOLOGY
PROGRAM

The study of the origin, evolution, and distribution of life in the universe is a broad, interdisciplinary endeavor that is the focus of the Life Sciences Division's Exobiology Program. Research sponsored by this program traces the pathways taken by the biogenic elements from the origin of the universe through the major epochs in the evolution of living systems and their precursors.

Cosmic Evolution of the Biogenic Compounds

The universe is at least 17 billion years old. Our sun and its planets were formed about 4.5 billion years ago from interstellar gas and dust. Gravitation and other forces cause clouds of gas and dust to contract, leading to the formation of stars. When some of these stars reach the end of their life cycle and explode (a phenomenon called a supernova), they distribute carbon and other heavy elements into interstellar space. The biogenic elements - carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur - cycle in and out of several types of environments within this medium, where physical forces bring about the creation of inorganic and organic compounds.

1989 Activities and Accomplishments

One important type of interstellar environment is the giant molecular cloud. These clouds are active nurseries for stars. More than 70 organic molecules and all of the biogenic elements have been detected in interstellar space, mostly within giant molecular clouds. The presence of large amounts of fairly complex organic molecules in these clouds has led to speculation regarding connections between these species and biological molecules on Earth. NASA-sponsored researchers recently reported the **first detection of an interstellar phosphorus-containing molecule and the tentative detection of a new species of organic molecule (HC₂CHO)**. Phosphorus is required for the synthesis of amino acids, the building blocks of life on Earth.

Comets and meteors are believed to be remnants of the formation of the solar system, and cometary and meteoritic impacts on Earth may have delivered volatiles and organic materials to its surface. Amino acids and other organic compounds with much different abundances than are normally found in our solar system have been found in some meteorites, an indication that these substances may have existed in the interstellar medium before our solar system formed. Analyses of dust collected during spacecraft encounters with Comet Halley in 1986 revealed the presence of a significant fraction of biogenic elements. Low-resolution infrared spectroscopy indicated that the cometary dust grains might contain organic compounds, but this interpretation is highly controversial.

Exobiologists are also examining interplanetary dust particles collected by high-altitude research aircraft. These particles are thought to be possible remnants of comets and asteroids dating back to the formation of the solar system; examinations have shown that they contain minute amounts of water. Interplanetary dust particles contain records of their genesis and alteration by various chemical and physical processes, but exposure to Earth's atmosphere and the high temperatures and pressures caused by hypervelocity impacts with collection devices may destroy or greatly modify some of this valuable information. Hence, **NASA researchers are evaluating various materials that might be used to collect intact, pristine dust particles or micrometeoroids on Space Station Freedom.**

The role played by comets in delivering biogenic elements and organic compounds to the primitive Earth is being studied by determining connections between the organic chemistry observed in molecular clouds in the interstellar medium and organic gases and solids found on icy bodies in the outer solar system, including cometary nuclei. Scientists at Ames are studying the presence of biogenic elements in the atmospheres and on the surfaces of solar system bodies such as comets. They are also **upgrading existing instrumentation** (gas chromatographs, for example) **and developing new, highly**

sensitive, miniaturized instrumentation for future flight investigations and ultimately for *in situ* chemical analyses.

Future Activities

In 1989, NASA selected an **intact cosmic dust collection experiment** for exobiology and a concept for an advanced cosmic dust collector to be developed as attached payloads on Space Station Freedom.

Exobiology flight investigations are planned for the Cassini mission to Saturn and Titan, for penetrators to reach the martian surface, and for an eventual Mars Rover/Sample Return mission. An exobiology instrument also has been selected for the Comet Rendezvous/Asteroid Flyby mission scheduled for launch in 1995.

Fossils on Mars?

A major challenge for the space life sciences in the 1990s and beyond is to explain the relationship between planets and life. Thus far, living organisms have been observed only on Earth, a relatively clement location within the solar system, and the only planet with an abundance of liquid water. Yet biogenic elements and compounds - the main constituents of living matter - have been observed in interplanetary and interstellar space and are common in varying quantities throughout the solar system, even in regions of the outer planets.

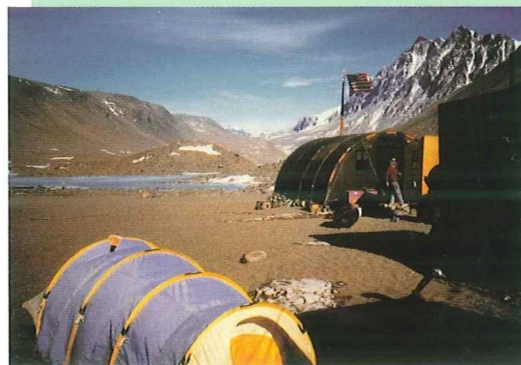
Some researchers hold the view that life is a planetary phenomenon which can and will modify a planet's surface and atmosphere to optimize conditions suitable for life. Comparative planetology could enhance our knowledge of processes operating on Earth and other planets, now and in the past.

Further exploration of Mars could add to the body of knowledge about processes governing the evolution of life on planetary

bodies. From the limited data now in hand, it appears that extant life does not exist on Mars. However, important questions remain to be answered: Did life develop billions of years ago on Mars and then become extinct? If so, why? If life never developed on Mars, why not?

Four billion years ago, the environment on Mars probably was comparable to that of the early Earth. Both planets had atmospheres composed primarily of carbon dioxide and nitrogen, and liquid water existed on the surface of each planet. Both planets contained the elements and compounds believed to play key roles in the origin of life. The implication is that just as life evolved on Earth, it also could have evolved on Mars. Sampling of the martian surface and subsurface will allow a detailed understanding of the extent to which chemical evolution occurred and biological evolution was possible.

Meanwhile exobiologists are looking to Antarctica as an Earth-based laboratory for studies relating to past life on Mars. One NASA-sponsored research group is studying communities of microbes that live in Antarctic rocks; this simple ecosystem is



In Antarctica, scientists are studying parallels between the early evolution of Earth and Mars.

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Antarctica may be used as a testbed for planning expeditions to Mars.

suitable for modelling and may be a terrestrial analog for possible past Martian life. The NASA research group built instrumentation to measure microbial conditions inside Antarctic rocks. Data was relayed continuously to the research team via satellite, and after three years of data collection and analysis the team has detailed information on how the rocks provide an environment that can support life.

Researchers are also using Antarctic lakes as analogs to the hydrological systems that may have been present on early Mars. Thermodynamic models of the ice cover on lakes in subfreezing climates indicate that a significant liquid water layer can exist under a relatively thin (three meters or so) ice cover as long as summertime peak temperatures are above freezing. Similar conditions could have prevailed on Mars in the distant past.

Gas-Grain Simulation Facility

Plans for future exobiology research include gas-grain simulation experiments in space. These experiments will address questions such as how complex organic molecules form in the interstellar medium, what happened to organic material in the pre-solar nebula during the contraction and heating of the nebula, and how matter from the formation of our solar system is related to organic material eventually incorporated into the planets during their formation. Understanding the origin of life and its relationship to patterns of stellar and planetary evolution will provide a basis for determining if life is widespread in the universe.

New technology is being developed to enable the study of such processes in a microgravity environment - a Gas-Grain Simulation Facility (GGSF) that will support investigations of particle-particle and gas-particle interactions on Space Station Freedom. Processes involving small particles are a major feature of many astrophysical and geological systems



throughout the solar system and the universe. Grain nucleation and aggregation, low-velocity particle collisions, and charge accumulation are some of the small-particle processes at work in atmospheric and interstellar clouds, planetary rings, and dust storms on Mars, for example.

Gravitational force on Earth is too great to ignore or subtract from experimental data gained from simulations of interstellar and nebular chemistry; the GGSF will extend the range of conditions for laboratory experiments - for example, it will be possible to reduce the effects of gravity by a factor of as much as one million, allowing small forces and electrostatic interactions to be studied without interference from large gravity fields.

The GGSF will allow controlled research on how gases and grains react and how grains accrete in space, allowing researchers to establish boundaries for organic synthesis during early solar system evolution. Research will include close measurements of the degree to which the rate of grain accretion into planetesimals, planetoids, and eventually into planets influences the formation of biogenic elements and compounds.

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These investigations are key to understanding the origin of life as it relates to planetary and stellar evolution. Gas-grain studies should also enhance scientific understanding of terrestrial processes such as acid rain formation, ozone depletion, and climatic change.

The GGSF will take up a Space Station Freedom double rack and include a 15-liter experiment chamber plus environmental controls; video cameras, spectrometers, and other measurement equipment; and levitation devices for positioning particles. The facility should be flight-ready in the late 1990s.

Prebiotic Evolution

The objective of research in prebiotic evolution is to understand how the evolutionary sequence leading from simple chemicals to living systems occurred during the development of Earth and other planets. There is a need to identify and characterize the role of novel energy sources in promoting prebiotic organic synthesis.

1989 Activities and Accomplishments

Life scientists are working on a geochemical flux model to investigate the transfer of carbon, nitrogen, oxygen, hydrogen, sulfur,

and chlorine species among the atmosphere, oceans, solid Earth, and emerging biosphere over geological time. They are studying the geochemistry, geology, and atmospheric chemistry of early Mars to better understand the early Earth and to assess the possibility of past life on Mars (*see p. 34*).

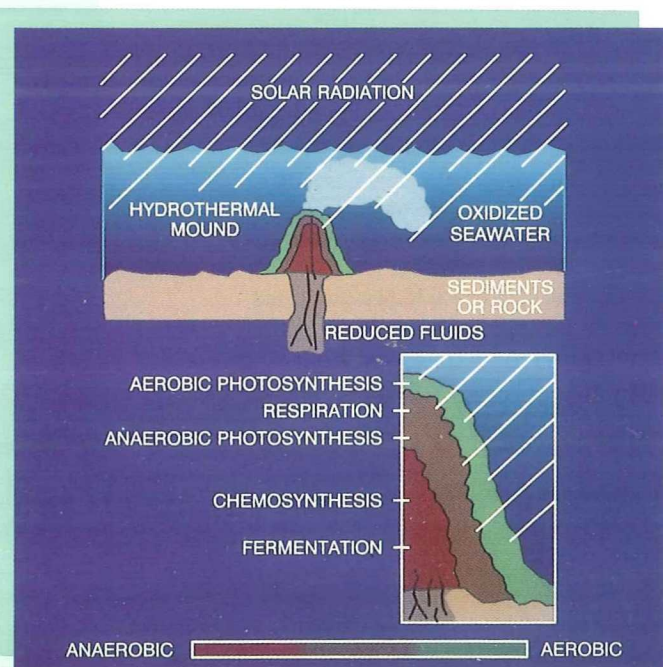
Titan, a moon of Saturn, may serve as a model of the atmosphere of early Earth in which the first stages of organic chemical evolution presumably took place. Voyager 1 observations showed that Titan has a nitrogen-dominated atmosphere, surface pressure greater than that on Earth, possibly a partially liquid surface (methane and ethane), and organic compounds (hydrogen cyanamide, cyanoacetylene, and cyanogen have been identified). Voyager 2 observations in 1989 verified the presence of organic materials on Titan. **Exobiologists are studying photochemical synthesis and reactions of cyanoacetylene in the atmosphere of Titan.** Cyanoacetylene is a compound that may have had a central role in the formation of biological molecules on the early Earth.

One major question regarding the origin of life is how nucleic acids developed the capacity to direct protein synthesis in prebiotic times, when complex subcellular structures were not present. Toward answering this question, the structure of transfer RNA is being studied by X-ray diffraction methods to elucidate its three-dimensional structure and its mode of action during polypeptide synthesis. Exobiology researchers are also **attempting to determine the molecular basis for the origin of the genetic code and the process of protein synthesis.**

One NASA-sponsored investigation examines the creation of prebiotic polymers or proteinoids, precursors to proteins that exhibit a tendency to organize into cells. This investigation has accomplished the first plausible laboratory retracement of the transition from inanimate matter to polybiofunctional protocells. Related investigations focus on the formation of vesicles, precursors to cell membranes that develop naturally from abiotic materials.

Some exobiologists are studying the possibility of the origin of life in deep-sea hot springs.

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NASA scientists are studying microbial mats for clues into the origins of life.

Early Evolution

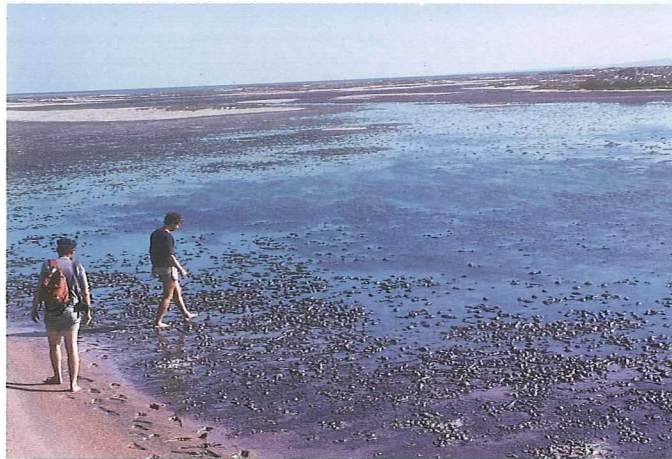
Life on Earth began 3.5 billion to 4 billion years ago in the form of complex anaerobic bacteria fueled by photosynthesis. In 1.5 billion to 2 billion years, these early life forms produced an oxygen-containing atmosphere on Earth. The goal of research into the early evolution of life is to determine the nature of the most primitive organisms, the environment in which they evolved, and the way in which they influenced that environment. One major goal in the study of the origin and early evolution of life is to infer the nature of the earliest replicating cells. Research focuses on investigating the molecular record in living organisms and the geological record in rocks, two natural repositories of evolutionary history on Earth.

Research sponsored by the Exobiology Program addresses questions such as how the interaction of sunlight with water vapor affects the production of atmospheric oxygen and ozone, how the process of photosynthesis evolved, how atmospheric nitrogen first was fixed (converted to a biologically useful form) by living organisms on Earth, and how the development of an oxygen-rich environment influenced the further evolution of the biosphere. It is also investigating the relationship between primitive bacteria and the evolution of Earth.

1989 Activities and Accomplishments

Microbial mats, modern homologs of ancient biological communities, are under study for clues about conditions in the ancient biosphere. **A team at Ames Research Center is studying microbial mats** at Laguna Ojo de Liebre off the Baja California peninsula. Another NASA-sponsored investigation focuses on understanding how microbial ecology and evolution affected the atmosphere and surface sediments of Earth during the Archean and Proterozoic eons.

Researchers are using theoretical **models of atmospheric chemistry and climate on the early Earth to simulate conditions under which life may have originated and evolved.** Similar models are being applied to the study



of Venus and Mars. A one-dimensional, radiative-convective climate model was used to estimate the width of the continuously habitable zone (CHZ) around the sun, and the conclusion was that the CHZ might be much wider than originally thought, indicating habitable planets might be relatively frequent occurrences.

Evolution of Advanced Life

Research into the evolution of advanced life seeks to identify external factors influencing its development and potential distribution. Researchers are attempting to determine the effects of global events and events originating in space on the production of environmental changes that affected the evolution of advanced life. Studies of the relationship between mass extinctions in Earth's distant past and impacts of large asteroids or comets on Earth will provide a better understanding of evolution.

1989 Activities and Accomplishments

NASA is sponsoring the development of a **high-resolution, fully computerized paleontological database** on 30,000 fossil marine animal genera, to be used in studying the history of extinction. Existing paleontological data bases are fragmentary and not constructed according to standardized criteria; the new data base will incorporate information sets not normally associated with paleontology, to enable the testing of hypotheses linking events in space with changes in the terrestrial environment and in turn with the process of biological evolution. Preliminary studies support evidence for a 26-million-year periodicity to mass extinction. They also indicate that extinctions in the geologic past were considerably less selective

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Radio frequency interference was measured at the Arecibo, Puerto Rico, observatory in 1989.

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than anticipated; it appears that all major biologic groups have essentially the same extinction history.

Exobiologists are also studying the **probability of intelligent life beyond our solar system**. Modern astrophysical theories indicate that planets may be the rule rather than the exception around the stars in our galaxy. Biological theories predict that, given enough stability on a planet, life, intelligence, and technology may evolve. The Earth is proof that this sequence has occurred at least once. Current theory holds that planetary systems around stars that are like our sun are potential "life sites." These theories have led NASA to plan a search for signs of extraterrestrial intelligence.

Future Research

Astronomers have long agreed that the naturally quiet microwave portion of the electromagnetic spectrum is the most practical place to begin searching for signals from extraterrestrial technology. On Columbus Day 1992, in honor of the 500th anniversary of Columbus' discovery of America, NASA plans to initiate the **Search for Extraterrestrial Intelligence Microwave Observing Project (SETI MOP)**. The objective is to search the microwave spectrum at high sensitivity and high speed, in real time, for radio signals of extraterrestrial intelligent origin. The search will be conducted in two modes - a sky survey that will sweep the celestial sphere for signals, and a targeted search that will look at about 800 nearby sunlike stars. The sky survey will cover a larger area and frequency range than the targeted search, but the targeted search will be significantly more sensitive. NASA's Deep Space Network will be used for major portions of the targeted search and sky survey, and other observatories will participate as needed

and feasible. A NASA Research Announcement is forthcoming to invite U.S. and foreign participation in the SETI project.

Technology Development

The SETI system combines highly sensitive signal receivers with fast, efficient signal processing programs that can sift through background radio noise (radio frequency interference, or RFI) for patterns indicative of ETI signals much more easily. SETI researchers drafted an RFI survey plan in 1989, because the RFI environment to be encountered at observatory sites during the observational phase of the Microwave Observing Project is at present largely unknown. Meanwhile, JPL is conducting an RFI survey in the vicinity of the Goldstone complex to establish RFI trends and ensure that the SETI sky survey attains sufficient sensitivity to overcome the RFI problem.

From 1985 to 1987, the first-generation prototype of a Multichannel Spectrum Analyzer (MCSA 1.0) for the targeted search, featuring 74,000 channels, was tested at NASA's Deep Space Network station near the Jet Propulsion Laboratory. The MCSA 1.0 was able to detect a one-watt signal transmitted from outside the solar system by NASA's Pioneer 10 spacecraft. In 1989, the MCSA 1.0 and a prototype Radio Surveillance Subsystem were installed at the Arecibo Observatory in Puerto Rico for field tests. A second-generation prototype, MCSA 2.0, featuring a custom-made very large scale integration (VLSI) chip that permits increased signal processing speed and performance in 15 million channels while greatly reducing the scale of the hardware system, will be field-tested in the fall of 1990, along with a prototype sky survey system. The prototype systems will be upgraded for the initiation of the SETI MOP in the fall of 1992.

PROMOTING GOOD SCIENCE AND GOOD WILL

INTERNATIONAL
COOPERATION
IN THE SPACE
LIFE SCIENCES

Life sciences research is inherently global; advances in the field offer benefits to all of humankind. In the future, exploration of outer space may not be possible without international cooperation, and the Life Sciences Division is laying the groundwork for such initiatives through several cooperative programs.

1989 Activities and Accomplishments

In addition to the U.S.S.R., several other countries are engaged in cooperative activities with the Life Sciences Division: the French space agency Centre Nationale d'Etudes Spatiales (CNES), the German space agency DLR, the National Space Development Agency (NASDA) of Japan, the Canadian Space Agency (CSA), and the European Space Agency (ESA).

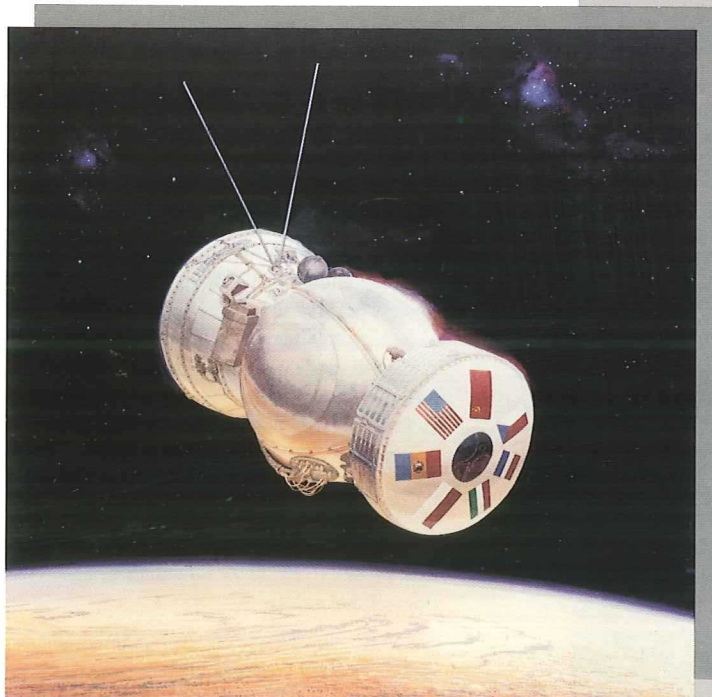
More than 80 NASA-sponsored researchers from 19 states and three foreign countries participated in 29 **cooperative investigations on a Cosmos biosatellite mission launched by the U.S.S.R. in September 1989**. The Cosmos biosatellite is an unpowered recoverable spacecraft that accommodates plant and animal experiments and the 1989 mission was the seventh Soviet biosatellite mission in which the United States played a role. Cooperative investigations on the 14-day Cosmos '89 mission questions related to the biomedical effects of prolonged space flight. Biological specimens on the mission included rhesus monkeys, rats, fish, fish eggs, newts, drosophila, beetles, seeds, unicellular organisms, and planaria. Investigations covered bone and muscle alterations, circadian rhythms and thermoregulation, neurophysiology, radiation biology, and gravitational biology.

Nearly 3,000 biological samples from the Cosmos '89 flight and control groups of subjects were returned to laboratories across the United States for analysis. Soviet biomedical investigators are participating in a similar biospecimen sharing plan for NASA's Spacelab Life Sciences 1 mission (*see p. 13*).

The Cosmos 1887 mission launched on September 29, 1987, involved 60 U.S. investigators in cooperative experiments that yielded data on radiation dosimetry; changes in rodent bone, muscle, and organs; and bone tissue calcium loss in primates. Results of those investigations were announced at a science symposium in Moscow in late 1988. The U.S.S.R. has invited the United States to participate in cooperative investigations on the next Cosmos biosatellite mission as well.

The International Microgravity Laboratory 1 mission, a cooperative Space Shuttle/Spacelab flight, will carry a diverse payload of life science and microgravity science experiments from several countries. The life science **payload for IML-1, which was confirmed for flight in July 1989**, consists of 29 experiments from NASA, the European Space Agency, Japan, and Canada. These experiments will use a variety of species as test subjects, and samples will be taken from crew members as part of the Life Sciences Division's continuing effort to describe human adaptation to space.

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U.S. investigators participate in experiments on the Soviet Union's Cosmos biosatellite missions.

Interagency Cooperation

A NASA-National Institutes of Health Joint Working Group was established in 1989 to pursue opportunities for joint research in space medicine and biology. The first meeting of this group took place in early 1989. **In the fall of 1989, NASA and the NIH's National Institute on Aging held a joint workshop** to discuss commonalities between the study of the aging process and the study of physiological deconditioning in space and possibilities for joint research in these areas.

In 1989, NASA officials began discussions with representatives of the Environmental Protection Agency regarding interests in joint research into the effects of global warming on aquatic systems. A memorandum of understanding has been drafted under which NASA's Life Sciences Division would provide biological research expertise, NASA's Earth Science and Applications Division would provide aerial remote sensing service, and the EPA would provide funding.

In cooperation with the National Oceanic and Atmospheric Administration and Farleigh Dickinson University's National Undersea Research Center, life scientists at NASA's Ames Research Center are studying how crews live and work in the Aquarius undersea habitat as an analog to Space Station Freedom. Crews of oceanographic researchers live for seven to 14 days at a time in the Aquarius underwater habitat, located off St. Croix in the U.S. Virgin Islands. NASA researchers collected data on six Aquarius teams in 1988 and plan to study up to nine teams in 1989. Before entering the habitat, team members complete personality tests and other social/organizational questionnaires. During and after their dives, team members record observations of performance measures such as task productivity, crew satisfaction, and operational safety.

Spacebridge to Armenia: Space Technology and International Cooperation Aid Disaster Victims

In December 1988, a powerful earthquake devastated Soviet Armenia. Of four cities in the disaster zone, the two hardest hit were Leninakhan and Spitak; 700,000 people resided in the disaster area. At a time when medical aid was most needed, hospitals and clinics were destroyed or in disarray and doctors working around the clock were dealing with deaths and injuries in their own families.

On December 22, 1988, not long after the earthquake occurred, NASA presented the Soviet government with an official offer of telecommunications assistance to the victims of the disaster. The intent was to establish a telemedicine Spacebridge to relay U.S. medical advice and assistance via satellite in real time to doctors in Armenia. The Soviet Union accepted NASA's offer in late February, and U.S. and Soviet physicians and communications specialists met in Moscow and Yerevan, Armenia, in March and signed an agreement to establish a Spacebridge. This cooperative endeavor was planned under the auspices of the 1987 U.S.-U.S.S.R. space cooperation agreement, as an activity of the U.S.-U.S.S.R. Joint Working Group on Space Biology and Medicine.

Linked by satellite, the doctors using the Spacebridge had access to audio, visual, and fax communications capability at NASA Headquarters, the Republic Diagnostic Center in Yerevan, Armenia (outside the disaster zone), the Uniformed Services University of the Health Sciences in Bethesda, Maryland, the University of Maryland Institute of Emergency Medical Services System in Baltimore, the University

of Texas Health Science Center in Houston, and the University of Utah and LDS Hospital in Salt Lake City.

From May 1 to June 30, dozens of physicians met from 9 a.m. to 1 p.m. EDT (6 p.m. to 10 p.m. Armenian time), Monday through Friday, to discuss difficult medical cases resulting from the Armenian disaster. Each day, Armenian doctors prepared their cases according to an agenda that set the subject for each day's consultation, faxing data on the cases to U.S. participants before each session began. During the consultations, Armenian doctors presented their cases one by one, sometimes with the patient on hand, displaying x-rays, CT scans, and other relevant data. Doctors at the U.S. medical centers then made recommendations for treatment or further study. Many of the cases discussed were injuries requiring reconstructive or plastic surgery, orthopedics, or prosthetics. Post-traumatic stresses also accounted for a lot of cases requiring psychiatric or psychological treatment. Many consultations focused on public health issues such as sanitation problems and epidemiological concerns.

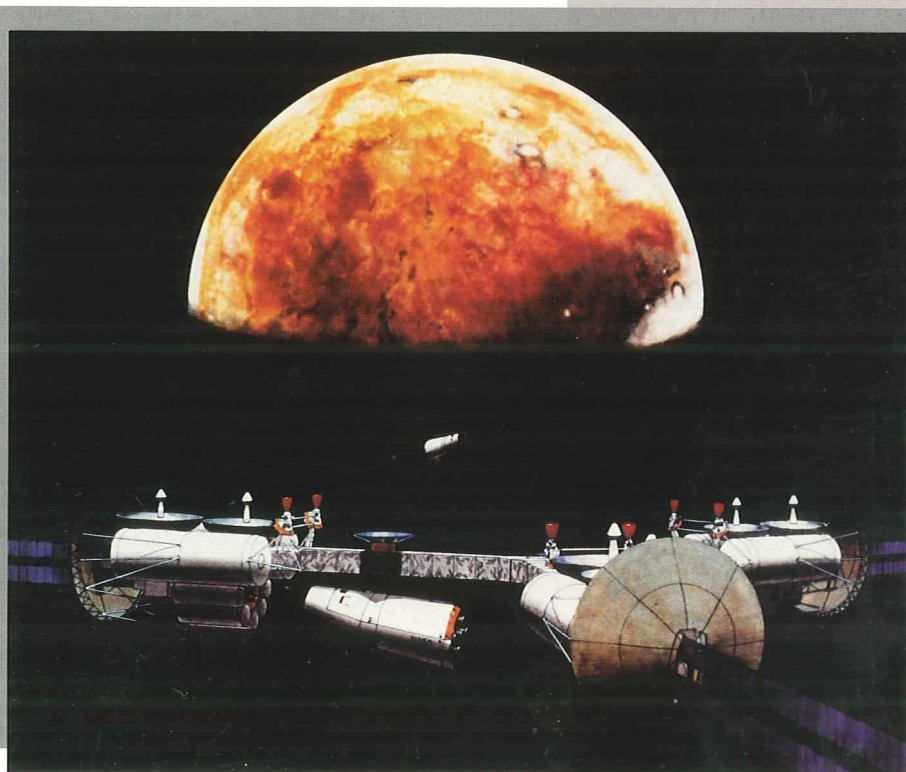
The spacebridge to Armenia turned out to be such a successful endeavor that, in June 1989, the United States and the Soviet Union decided to extend the spacebridge to tend to the victims of another disaster. Severe burns were a problem for many of the victims of an accident in which two trains were destroyed by a gas explosion outside the Soviet city of Ufa in the Ural Mountains in May. Spacebridge links were extended to Moscow and Ufa to provide access to U.S. medical expertise, especially in the field of burn treatment.

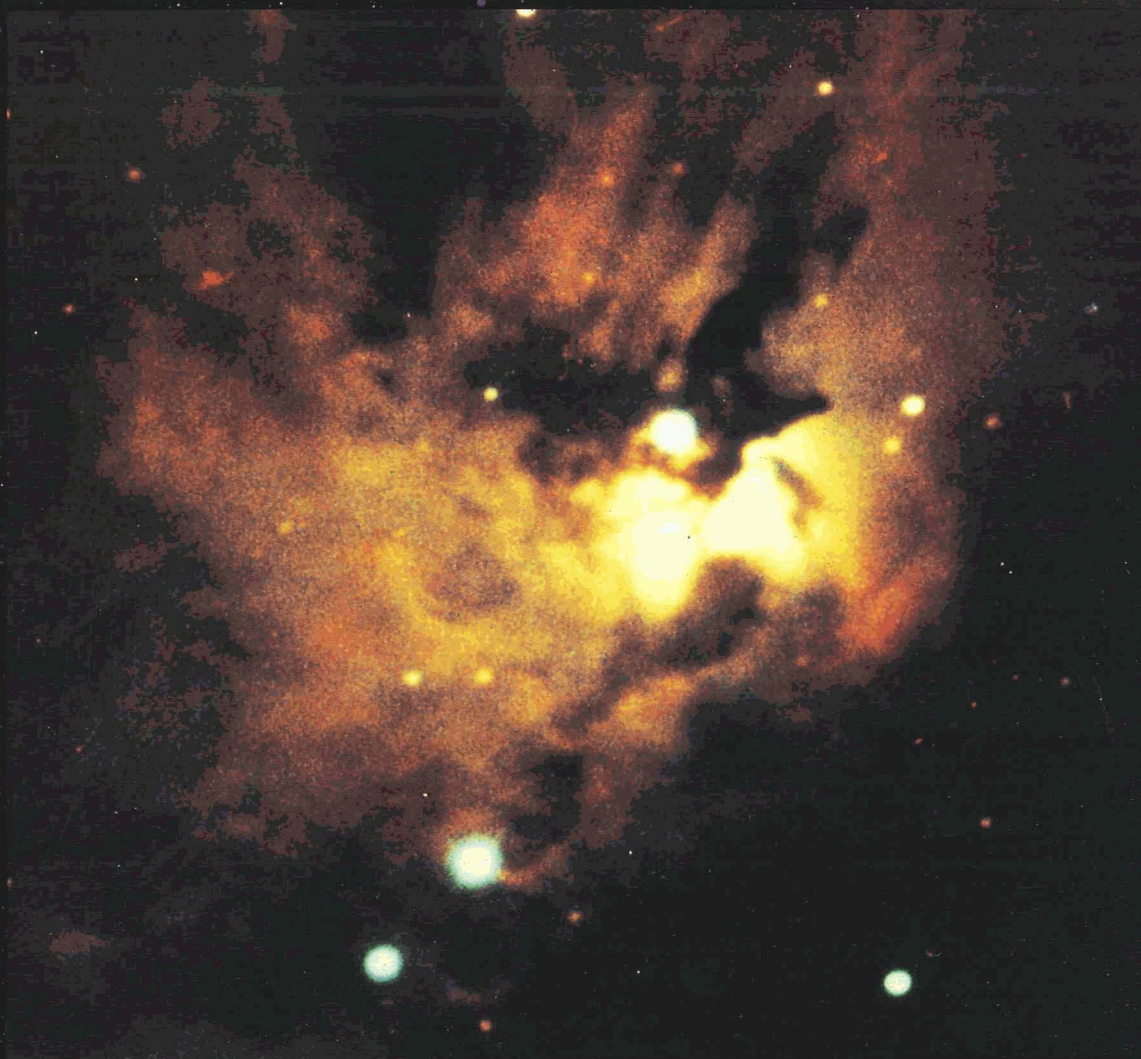
A human expedition to Mars could be an international cooperative endeavor.

Spacebridge participants now know how to conduct a complicated telemedicine consultation, and this knowledge will be useful in future emergencies. The experience will also be useful in planning for telemedicine consultations on future space station missions. And the success of the Spacebridge can only help to foster good relations between the two countries. A medical school curriculum for teaching telemedicine techniques may be developed based on the U.S.-U.S.S.R. Spacebridge experience, and the United Nations Committee on the Peaceful Uses of Outer Space will be briefed on the Spacebridge in February 1990.

NASA's Goddard Space Flight Center was responsible for the operation of the Spacebridge; Satellite Transmission and Reception Services, Inc. (STARS) of Houston provided a transportable ground station as well as technicians for the Yerevan center; AT&T and Intelsat/Comsat donated on-orbit communications service; and Bendix provided operational support.

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BUILDING A FUTURE FOR THE SPACE LIFE SCIENCES

EDUCATIONAL
ACTIVITIES

The Life Sciences Division sponsors a wide range of educational programs aimed at interesting elementary, secondary, college undergraduate, and graduate and post-graduate students in the space life sciences. The point is not only to further the education of these students but also to attract students to the space life sciences and ensure that a pool of talented, trained individuals is available to support the space life sciences program in the future. Two new educational activities initiated in 1989 are program linked to the Spacelab Life Sciences 1 (SLS-1) mission and an elementary and secondary school science education campaign linked to the Search for Extraterrestrial Intelligence Microwave Observing Project.

1989 Activities and Accomplishments — High School Curriculum

A pilot Spacelab Life Sciences 1 (SLS-1) curriculum development program will give thousands of high school students an opportunity to participate in the first Space Shuttle/Spacelab modular mission to fly since 1985, and the first Shuttle mission dedicated entirely to life sciences research. The **SLS-1 Educational Project, Human Physiology in Space: A Program for America**, cosponsored by the National Institutes of Health, will produce curriculum supplements for high school biology, health science, and physiology programs. Products will include a teacher's manual and a student's mission experiment manual. Before launch, scheduled for the second half of 1990, high school students will be provided their mission experiment manuals, which will explain experiments on SLS-1 that will examine what happens to the human body in microgravity. The manuals will enable students to follow mission events as informed observers; a follow-up program is planned for later years that will explain the results of the SLS-1 experiments and prepare students to participate in the SLS-2 mission.

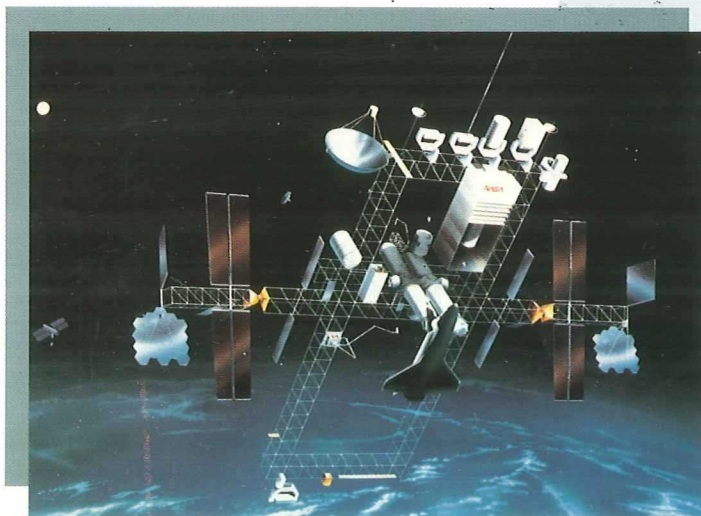
Future research opportunities on the Space Shuttle and on Space Station Freedom attract students to the space program.

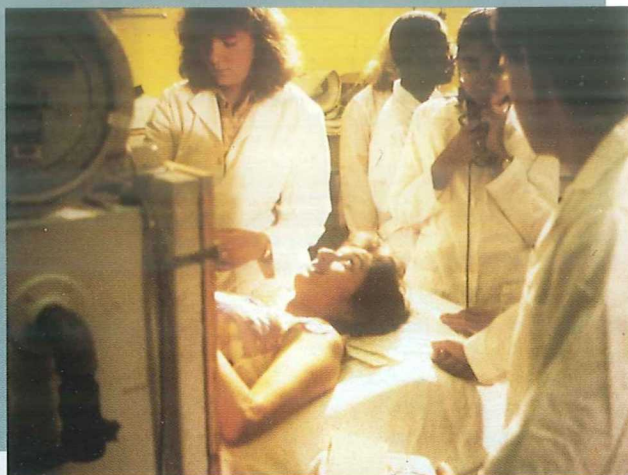
New Mexico high schools have been chosen as the primary sites for participation in this pilot project. New Mexico high school science teachers are involved in the development and review of the curriculum materials; CISCO-NET, a computer information network established for New Mexico science teachers, will be used to help disseminate information on the project. The potential for a much more extensive, possibly nationwide project in the future rests on the success of this pilot effort.

1989 Activities and Accomplishments — Elementary Programs

The staff of the SETI Microwave Observing Project developed a **program to teach the elements of life in the universe to grade-school children** and tried it out in a Redwood City, California, school in early 1989. Posters, brochures, and other informational reports about SETI and the study of life in the universe are being widely distributed to elementary and secondary school teachers around the country to assist them in interesting students in biology, chemistry, physics, astronomy, and computer science. Thousands of informational posters about SETI were distributed at the 1989 conventions of the National Science Teachers Association and the National Council of Teachers of Mathematics. The SETI project office at NASA's Ames Research Center intends to transfer database information on SETI to NASA's Spacelink Database for Educators.

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College undergraduates spend a summer attending classes and working at the Kennedy Space Center in the Space Life Science Training Program.

In the summer of 1989, SETI officials participated in a "Space Down to Earth" workshop for teachers and administrators at the Ames Research Center, organized by Ames's Educational Affairs Office. They have also offered information and assistance to the National Science Foundation's Triad Program, which designs science curriculum materials for teaching math, science, and technology in grades K through 12. The SETI staff are also developing curriculum materials for the NEWMAS program — NASA Education Workshops for Math and Science Teachers. This program, sponsored by NASA, the National Science Teachers Association, and the National Science Foundation, offers two-week summer workshops at NASA field centers for outstanding math and science teachers.

1989 Activities and Accomplishments — College Programs

The Life Sciences Division's Biospheric Research Program sponsors a **Planetary and Microbial Ecology Program** to provide advanced graduate students and experienced scientists with training in the theory and practice of assessing how microbial activity affects Planet Earth. The goal of the program is to promote the development of a community of scholars who will pursue interdisciplinary research toward an understanding of the influence of living organisms on water, atmosphere, and sediments. The program entails a six-week intensive course for 14-16 students per year; it features lectures by visiting specialists as well as laboratory and field work in biogeochemical cycling of the biogenic elements. In 1989, a new feature was

added to the program: intensive field work to collect ground truth data for verifying remote sensing imagery.

The Space Biology Research Associate Program, funded by the Life Sciences Division's Space Biology Program, is open to applicants with PH.D., M.Sc., M.D., D.D.S., or D.V.M. degrees. Awards are made for independent projects to be conducted at the university of the applicant's choice. The program began in 1980, and it now involves 59 research laboratories around the country. Scientists funded under this program have worked in the fields of zoology, developmental biology, botany, and physiology.

The Planetary Biology Intern Program, funded by the Division's Biological Systems Research Branch, provides opportunities for graduate students to take part in planetary biology research at universities and NASA field centers. Interns work with NASA-sponsored investigators for eight weeks during the summer. Graduate students and senior undergraduates with exceptional records are eligible. The program is managed by Boston University's Department of Biology. The Planetary Biology Internship Program provides opportunities for students to explore scientific questions through research projects related to NASA's planetary exploration goals. Since 1980, this program has sponsored approximately 10 interns per year, providing them an opportunity to work with members of NASA's scientific community.

To promote post-graduate education, the Life Sciences Division is one of several organizations that sponsor candidates in an **Aerospace Medicine Residency Program** run by Wright State University in Dayton, Ohio. This program involves an optional third-year rotation through a NASA center and leads to board certification in aerospace medicine.

N-SCORTs

In 1990, the Life Sciences Division will begin issuing grants to establish **NASA Specialized Centers of Research and Training** (N-SCORTs). Multidisciplinary N-SCORTs,

at single universities or consortia of cooperating institutions, will support a mix of pre- and post-doctoral fellows, project investigators, and senior scientists. The NSCORT Program is being established as an integral part of the Life Sciences Division's research and analysis activities. The Program is intended to advance basic knowledge and, at the same time, generate effective strategies for coping with and, eventually, solving specific problems in selected research areas within the space life sciences. Ultimately a total of 10 N-SCORTs will be supported.

The NSCORT Program is expected to further the Nation's scholarship, skills, and performance in the space life sciences and related technology areas. It also should enhance the pool of research scientists and engineers training to meet the considerable challenges of the Nation's commitment to prepare for future human space exploration missions.

SLSTP: OPENING DOORS TO CAREERS IN SPACE

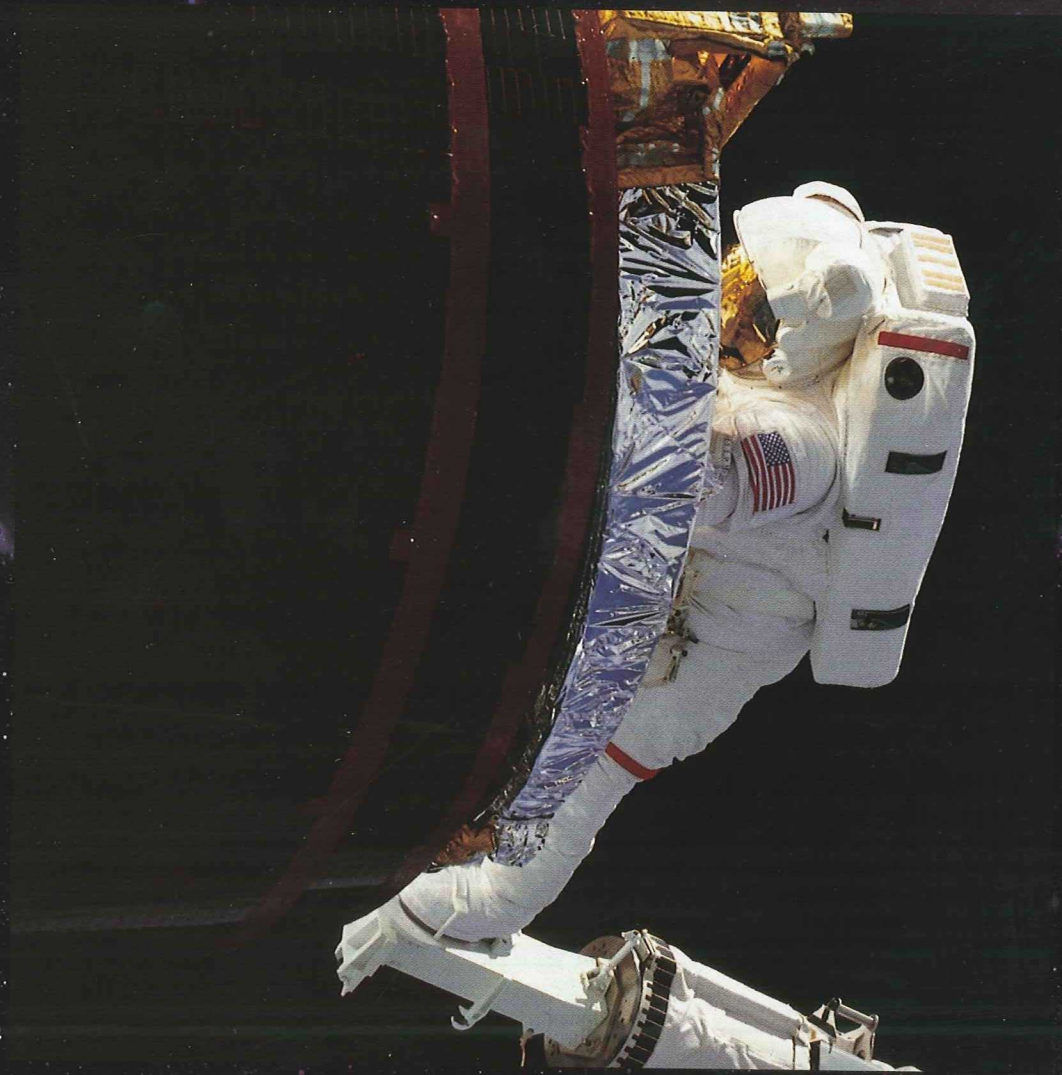
The summer of 1989 marked the fifth anniversary of the **Space Life Sciences Training Program**, jointly funded by the Life Sciences Division and NASA's Office of Equal Opportunity Programs to give college undergraduate students a chance to learn about the space life sciences, work on flight experiments, and consider careers in the space life sciences.

The SLSTP is a six-week intensive training course held in the summer at NASA's Kennedy Space Center and managed by Bionetics Corporation and Florida A&M University's College of Pharmacy and Pharmaceutical Sciences in Tallahassee. Minority students are encouraged to apply. Each year, 30 to 40 students are enrolled in the program, earning five semester hours of credit. Students work with NASA researchers on flight experiments, learning about teamwork, project schedules, and special considerations in space experimentation and microgravity constraints, including physiological adaptation to space. The SLSTP curriculum includes a microgravity work-

shop, classes on the fundamentals of space flight and living and working in space, and instruction in statistics and experimental design.

In 1989, students worked on a variety of investigations. A controlled ecological life support system project allowed students to study wheat micropropagation — the use of wheat tissue culture instead of seeds to grow the crop, fungal enzymes to convert inedible biomass into edible sugars, alternatives to high-pressure sodium lamps for plant growth lights; and different designs and materials for plant nutrient delivery systems. A cardiovascular physiology project gave students a chance to validate a new noninvasive technique for measuring peripheral blood pressure (a cuff similar to the arm sphygmomanometer that most doctors use to measure a patient's blood pressure) and use the new technique to study blood pressure adjustments that may be a part of the cardiovascular reflex to body fluid shifting. Students also tested prototype hardware for a sea urchin embryo development experiment to fly in space; fertilization, cell proliferation, and skeletal calcium deposition are among the phenomena to be observed in the absence of gravity. This summer, students verified the hardware design for the sea urchin experiment — a "bag in a box," or a semipermeable membrane (the bag) to help maintain dissolved gas concentrations placed in a container (the box).

By 1990, 162 students will have completed the SLSTP course. More than 50 percent of participating students thus far have reported that the program led them to redirect their career goals toward space-related fields, and about 40 percent have reported that the program informed them about many research and career opportunities they had not previously thought about. Students have also said that the program heightened their awareness of their own individual capabilities. Some graduates have already found work in the space program. The SLSTP also brings in graduate students to serve as project and curriculum assistants, and this experience has helped some of them find careers in aerospace — six former assistants now work at KSC.



TOWARD A BETTER LIFE ON EARTH

BENEFITS OF SPACE LIFE SCIENCES RESEARCH

While NASA's Life Sciences Program is focused on ensuring crew health and safety during space flight and studying adaptation during long-duration space missions, research sponsored by the program often has applications to those still on the ground. Biomedical research may lead to treatments for debilitating conditions afflicting people here on Earth. And fundamental research conducted under the Space Biology Program could add to the store of knowledge about the role of gravity in life.

Countermeasures to be developed for physiological deconditioning in space may be of benefit in combatting cardiovascular illness, muscle deterioration, and other types of physiological deconditioning on Earth. The Life Sciences Division's Extended Duration Orbiter Medical Program (*see p. 9*) will develop and verify procedures and countermeasures designed to optimize crew performance on EDO Shuttle missions. To achieve this objective, NASA life scientists will develop special exercise equipment that will be efficient, quiet, low-vibration, and portable. In addition, innovative exercise protocols will be developed for maximum conditioning in a minimum period of time. The development of more efficient and effective exercise equipment and techniques will be of great benefit in the treatment and prevention of cardiovascular disease, the leading cause of death in the United States, because greater physical fitness decreases the risk of such disease. NASA ultimately should be able to make available **improved exercise equipment** targeted to critical muscle groups and coupled with **highly effective exercise protocols**.

Immobilization is often a necessary component of intensive medical care of trauma victims and patients with acute illnesses; it may have profound effects on these patients' metabolisms. NASA-sponsored bedrest studies and other biomedical investigations of physiological deconditioning may yield **pharmaceutical and other treatments for bone and muscle deterioration**. For example, a research team sponsored by JSC has validated the seven-day bedrest study as a model of human muscular inactivity during space

flight. This team has documented significant measurable muscle weakness and deterioration during seven days of bedrest. Rates of protein breakdown and synthesis have been measured before and after bedrest. The team has also measured changes in anabolic (growth-promoting) and catabolic hormones brought on by bedrest and also characterized bedrest-related changes in glucose metabolism: insulin-stimulated glucose use decreased significantly during seven days of bedrest.

An anti-motion-sickness technique being developed for space crew members may have further Earth-based applications. Scientists at NASA's Ames Research Center have devised an autogenic feedback training (AFT) procedure — a learned method of self-regulation of the autonomic nervous system — for the prevention of space motion sickness. Along with investigators at Yale University, they have submitted a proposal to the American Cancer Society to sponsor tests of these AFT techniques as a **possible countermeasure for chemotherapy-induced nausea** and vomiting in cancer patients. Hardware developed for this research project also has potential applications outside the space program. An ambulatory monitoring system developed for AFT experiments in space enables continuous recording of up to nine channels of physiological responses over an 18-hour period; it should be useful in many medical applications. In collaboration with researchers at the University of California in Los Angeles, AFT researchers plan to develop and test a computer-controlled blood pressure tracking system, a non-invasive device that will allow beat-to-beat tracking of systolic and

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*Space biomedical research
may yield solutions to health
problems on Earth.*

diastolic blood pressure in humans and that should be useful in medicine and medical research outside the space program.

A NASA-sponsored research project intended to improve the diagnosis, prevention and treatment of motion sickness has yielded a new device with Earth-based medical applications. To better define the physiological changes and time course of sensations in motion sickness, researchers emphasized the development of new methods for monitoring the physiological signs of motion sickness. They developed a pulsed infrared reflectance device for measuring skin blush and pallor, which flew on Space Shuttle missions STS 7 and 8, and subsequently applied for a U.S. patent on the device. The patent has been granted, and a private company, a subsidiary of Laserlight Inc., has purchased the rights to develop a commercial version.

The device, which measures skin pallor as the percentage of infrared reflectance of the skin, consists of a miniature gallium arsenide light-emitting diode providing pulsed infrared light, a silicon photodiode detector, and processing circuitry. It also features circuits that measure average blood volume, pulse amplitude and heart rate, and an adjustable source pulse amplitude that standardizes the amount of light reflected to the detector so that the device works equally well on dark and light skinned individuals. Changes in skin pallor signal motion sickness, nausea, and shock, presumably caused by changes in the volume of blood in the microcirculation of the skin. Hospitals should find the NASA **skin-pallor device** particularly useful during surgical operations, in recovery, and in intensive care units to **detect the onset of shock**, nausea, syncope and related illnesses. In addition, the device may be useful in diagnosing Raynaud's syndrome and other circulatory disorders.

The Life Sciences Division's Advanced Technology Development Program is funding some projects with commercial potential. New **biochemical sensors** — very tiny instruments that can easily be implanted or inserted into the body of a research subject — will permit investigators to measure concentrations of ions

such as calcium, sodium, and potassium in real time, in space or on the ground. In space, crew members can use these sensors to make measurements that can be reported to investigators on the ground immediately. Calcium, sodium, potassium, and other ion concentrations can indicate physiological changes caused by exposure to microgravity — for example, if calcium in the blood continually increases during space flight, it is an indication of bone demineralization. Higher concentrations of all of these ions in the blood may indicate a loss of body fluids. The course of calcium or other substances ingested during an experiment can be tracked by using such sensors. These kinds of measurements will be extremely useful in studying microgravity deconditioning and developing countermeasures.

In 1989, Ames Research Center entered into a joint agreement with two private-sector partners, SRI (Stanford Research Institute) in Palo Alto and Commtech, a California venture capital company, to develop an implantable calcium ion sensor. The first prototype sensor will be delivered to NASA this year. NASA will use the sensor for biomedical investigations on space flights and in ground-based laboratories. The agency also retains the right to offer the technology to other federal agencies such as the National Institutes of Health. SRI plans to commercialize the technology; the sensor will be marketed to the medical community as a device that will enable rapid and accurate analysis of blood.

If this type of sensor proves effective for biomedical analyses, it could replace the traditional method of collecting samples and sending them to a laboratory for analysis. On-site, real-time analysis with biosensors could also eliminate time-consuming and costly storage and shipping of degradable biological samples. Similar biosensors could be developed for analyzing urine and other fluids. Additional potential applications of this biosensor technology remain to be explored. For instance, it may prove useful for on-site, real-time analysis of drinking water or waste water in the public health and environmental protection fields.

Health care and life support equipment to be developed for interplanetary space missions could have applications on Earth.

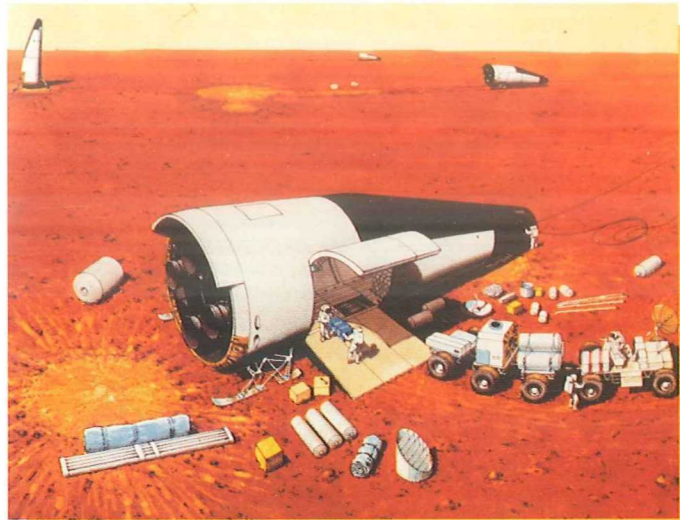
The ATD Program is also funding an evaluation of methods to reduce power requirements for Controlled Ecological Life Support Systems. As part of this evaluation, investigators at Ames Research Center are looking into the development of **highly efficient techniques for generating light** for plant growth in Controlled Ecological Life Support Systems.

The Ames group is discussing joint technology development with potential partners in the electronics industry. Such an initiative would develop light-emitting diode (LED) arrays for CELSS lighting. Such energy-efficient systems should have broad non-aerospace applications. LEDs can be a more efficient light source for plant growth because they can be manufactured to emit all of their light energy in the regions of the spectrum that best promote plant growth. Additionally, because their waste heat is not directed in the same direction as their emitted light, LEDs can be placed very close to the surface of plants or germinating seeds to promote faster growth with less light.

The Controlled Ecological Life Support System Program will be looking into automation and robotics techniques for growing crop plants in space, since crew time in space is too valuable to invest in tending plants.

Automated crop production methods will be of value to the commercial hydroponic farming industry, which could increase production and profits by increasing the level of automation. CELSS researchers are working on identifying environmental conditions that allow optimum yield and productivity; their findings will also be of use to the fledgling controlled environment agriculture industry.

Space-based biology investigations with plants could lead to improved plant growth systems that conserve soil, water, labor, and energy; improved manipulation of food storage protein and carbohydrate distribution, physiology and metabolism, and biomass production and partitioning in forest products, fiber, and fuel producing plants; breeding and genetic engineering of new plants; cloning of



pathogen-free plants; and production and separation of specific biochemicals from plant materials. Cloning from single cells may work better in space than on the ground because hormonal constraints on the process in one g are neutralized or more easily manipulated in space. Cloning of new types of plants in space that are difficult to propagate on Earth would be a boon to agribusiness.

Contributing to Competitiveness: Advanced Computer Technology Development

The Search for Extraterrestrial Intelligence Microwave Observing Project requires a high-speed digital signal processing system that can perform on the order of 10 billion operations per second, a rate that exceeds the speed of many existing supercomputers. NASA has already developed and demonstrated a prototype SETI Multichannel Spectrum Analyzer (MCSA) that can simultaneously process data in 74,000 channels. Also demonstrated, and now being further refined, is a second-generation MCSA that can process 15 million channels simultaneously at 1 Hertz resolution.

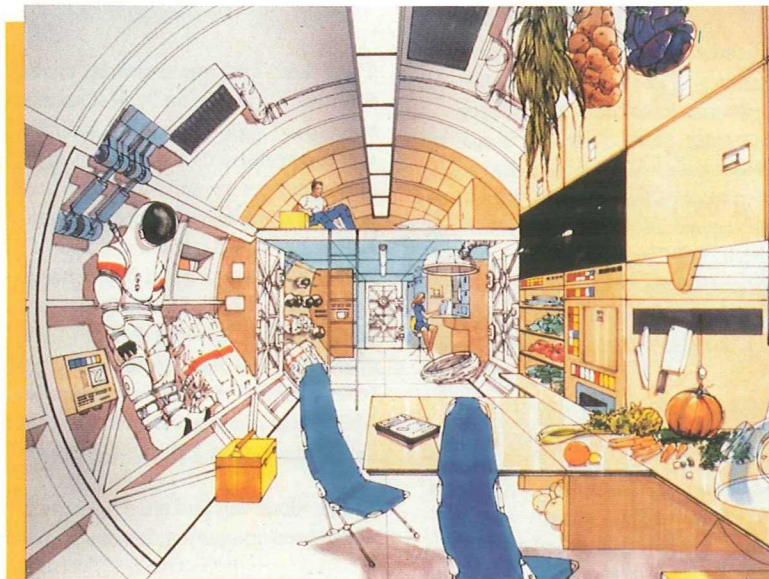
Tremendous demand already exists for high-speed computing, inside and outside of the space program. The 1989 Department of Defense critical technologies list includes two components of SETI technology development — ultra-small integrated circuits and ultra-high-speed parallel computing. New technology being developed

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for the SETI Microwave Observing Project should prove to have many applications outside of the space program. NASA researchers are developing two new types of very large scale integrated (VLSI) computer chips: a digital signal processing (DSP) chip to enable high-speed, high-volume processing, and a content-addressable memory (CAM) chip to enable pattern detection. The prototype SETI DSP chips, designed at Stanford University and produced through a program funded by the Defense Advanced Research Projects Agency, are faster than anything now available on the market—in fact, they are more than six times faster than the computer industry's current "workhorse," the Zoran VSP chip. With these new chips, funds—and space—required for the SETI project should be reduced by an order of magnitude compared to conventional computer architectures.

Many private-sector applications of SETI technology are worth exploring—for

example, higher-resolution processing of ultrasound signals used for medical diagnoses and exploration geology, without the need for costly supercomputers. In addition, the Federal Aviation Administration may be able to use SETI technology to improve air traffic control. The current air traffic control system must frequently respond to the need for identifying and locating spurious transmissions that interfere with ground-to-air communications. However, air traffic control technology now in use permits only the recording of such transmissions for later playback on limited frequency channels, and the sequential scanning of channels. This method of identifying and locating interference is not always as effective as FAA frequency spectrum managers would like it to be. The multichannel simultaneous signal processing provided by SETI technology would permit real-time signal detection, and FAA officials have expressed a strong interest in evaluating SETI prototype equipment.



The scientific research and technology development that will be required for human expeditions to Mars may produce many spinoffs for people here on Earth.

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**Academic and Research Institutions Conducting
NASA Life Sciences Research***

APPENDIX A

Arkansas

U. of Arkansas

Arizona

Arizona State U.

U. of Arizona

California

California Institute of Technology

Molecular Research Institute

Pomona College

San Diego State U.

San Francisco State U.

San Jose State U.

Stanford U.

U. of California

U. of San Francisco

U. of Southern California

Veterans Administration Medical Center

San Francisco

Colorado

Colorado State U.

Connecticut

Yale U.

District of Columbia

Naval Research Laboratory

Delaware

Delaware U.

Florida

U. of Florida

U. of Miami

Georgia

Emory U.

Georgia State U.

Illinois

Southern Illinois U.

U. of Chicago

U. of Illinois

Indiana

Indiana State U.

Indiana U.

Purdue U.

U. of Indiana

Kansas

Kansas State U.

Kentucky

U. of Kentucky

U. of Louisville

Louisiana

Louisiana State U.

Tulane U.

Massachusetts

Brandeis U.

Brigham and Women's Hospital

Harvard U.

Massachusetts Institute of Technology

Tufts University

U. of Massachusetts

Williams College

Woods Hole Oceanographic Institution

Maryland

National Council on Radiation Protection

Johns Hopkins U.

U. of Maryland

Maryland Institute of Emergency Medical

Services Systems

Maine

U. of Maine

Michigan

Michigan State U.

U. of Michigan

Wayne State U.

Missouri

St. Louis U.

U. of Missouri

Washington U.

Montana

Montana State U.

Nebraska

U. of Nebraska

North Carolina

Bowman Gray School of Medicine
Duke U.
East Carolina U.
U. of North Carolina
Wake Forest U.

New Hampshire

U. of New Hampshire

New Jersey

U. of Medicine and Dentistry of New Jersey

New Mexico

Los Alamos Scientific Laboratory
Lovelace Medical Foundation

New York

Brooklyn College
Columbia U.
Cornell U.
Helen Hayes Hospital
Mount Sinai Medical Center
New York U.
State University of New York

Ohio

Case Western Reserve U.
Kenyon College
Miami U.
Ohio State U.
Wright State U.

Oregon

Oregon State U.

Pennsylvania

Carnegie Mellon U.
Hahnemann U.
Pennsylvania State U.
Thomas Jefferson U.
University City Science Center
U. of Pennsylvania
U. of Pittsburgh

Rhode Island

Miriam Hospital

Tennessee

U. of Tennessee
Vanderbilt U.

Texas

Arlington Cancer Center
Baylor College of Medicine
Texas A&M U.
U. of Houston
U. of Texas

Utah

U. of Utah
Utah State U.

Virginia

Eastern Virginia Medical School
Virginia Polytechnic U.

Washington

Battelle Memorial Institute
U. of Washington
Washington State U.

Wisconsin

Marquette U.
Medical College of Wisconsin
U. of Wisconsin

West Virginia

U. of West Virginia

**partial listing*

Additional Reading

APPENDIX B

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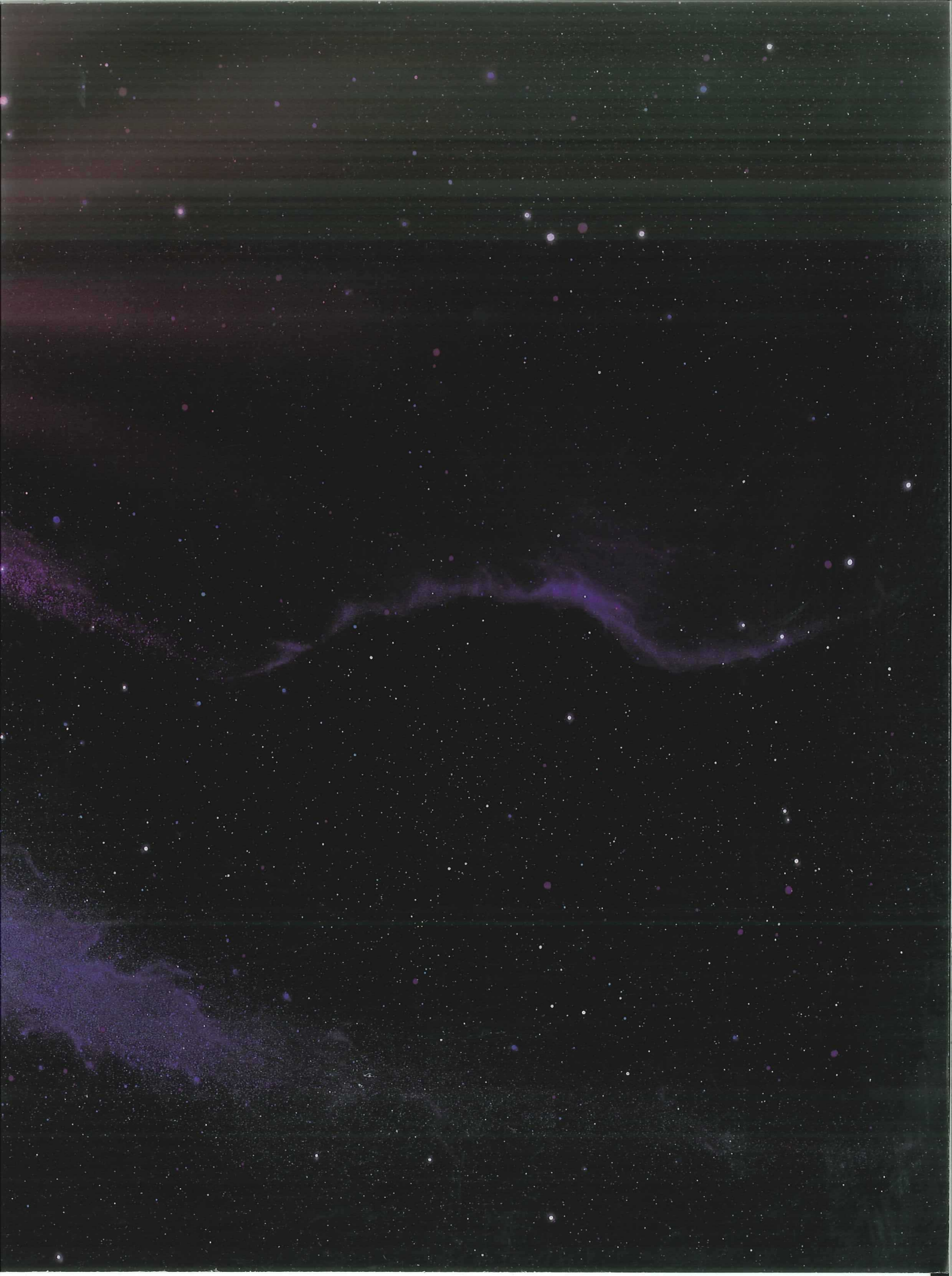
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Office of Space Science and Applications
NASA Headquarters